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DEVELOPMENT AND TEST OF THERMAL PROTECTION METHODS FOR BOMB FUZES TO EXTEND COOK-OFF TIME IN LARGE AIRCRAFT FUEL FIRES

By
Donald Levine

9 DECEMBER 1971

NOL

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DEVELOPMENT AND TEST OF THERMAL PROTECTION METHODS FOR BOMB FUZES TO EXTEND COOK-OFF TIME IN LARGE AIRCRAFT FUEL FIRES

Prepared by:
Donald Levine

ABSTRACT: (U) Both experimental and theoretical investigations have been performed on ways of extending the cook-off times of the Noze Fuze M904E2 and M148 Adapter Booster when engulfed in a liquid hydrocarbon fire. Several insulative materials were examined for utilization in fuzes and adapter booster fixes. The materials showing the greatest promise when fabricated into sleeves, were Candidates No. 10 and No. 14. These materials extended the cook-off times of the Fuze M904E2 with deflagration being the usual reaction. An open Adapter Booster problem was determined to exist. When the Adapter Booster was unprotected and flame was directed into the open cavity, cook-off resulted in approximately four minutes. When the Adapter Booster was protected with intumescent paint on the adapter ring, and a disc and washer of Candidate No. 10 was inserted into the booster cavity, times in excess of 12 minutes were obtained. When the two fixes were combined the times to cook-off, with a somewhat lower fire temperature, were in excess of 12 minutes with detonation being the reaction. This report describes the cook-off test procedures and discusses the laboratory and field results of cook-off fixes for Fuze M904E2 and M148 Adapter Booster.

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NOLTR 71-124 9 December 1971

Development and Test of Thermal Protection Methods for Bomb Fuzes to Extend Cook-off Time in Large Aircraft Fuel Fires

(U) NOLTR 69-112 and NOLTR 71-54 are previous reports that describe the cook-off characteristics of ordnance items when engulfed in a liquid hydrocarbon fuel fire. This report describes the results of a number of experimental and analytical investigations, supported by Task NOL-346/NMC Prob. No. 5, to extend the cook-off time of the Nose Fuze M904E2 and the M148 (T45E7) Adapter Booster. Based on an elimination process two (2) fixes for the M904E2 Fuze and one (1) fix for the M148 Adapter Booster were procured for evaluation. The recommendation for release to production of the chosen fix is contained in reference (4).

ROBERT WILLIAMSON II

Albert Lightbody
ALBERT LIGHTBODY
By direction

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INTRODUCTION

A great deal of interest has recently been expressed over the response of ordnance items to flame engulfment. Both the USS FORRESTAL and USS ENTERPRISE tragedies have intensified this interest. These fires have vividly demonstrated the hazards of a fire on the flight deck of an aircraft carrier. Following the USS FORRESTAL catastrophe, the Russell Committee, investigating this tragedy, recommended that a program be initiated to extend the cook-off times of this incident. In response to the committee's recommendations, Naval Ordnance Systems Command assigned the Naval Ordnance Laboratory the task of determining the feasibility of extending the cook-off times of the Mk 80 series of bombs to five (5) minutes.

Under the ground rules established by NAVORD the solutions selected for study were to (1) be economically feasible, (2) be compatible with loading plant operations and (3) employ materials commercially available. Theoretical and experimental test studies were conducted on many materials. As a result of this program a new high melting point asphalt was developed for the interior of the bomb cases. Coupled with this fix, was a commercially available intumescent paint, which was applied on the outer skin of the Mk 80 bombs. This combination of fixes gave times in excess of five minutes. Unfortunately, the commercial intumescent paint was not weather resistant and effort on other external coatings was necessary.

In December 1968, the cook-off program was shifted to Naval Air Systems Command (NAVAIR). NAVAIR continued investigations of other materials and systems to provide greater and more reliable protection for unfuzed Mk 80 bombs under varying environmental treatment and rough handling conditions.

In January 1970, NOL was assigned the task to investigate the cook-off characteristics of the Nose Fuze M904E2, commonly used in the Mk 80 series of bombs and to provide solutions to extending the cook-off time. Since detonations are more probable if the Fuze M904E2 initiates first, it is desirable to extend the cook-off times of the Fuze M904E2 to times longer than the main explosive charge. This report describes the cook-off studies of the Fuze M904E2 and M148 (T45E7) Adapter Booster.

THEORY

Basically, a large turbulent fully developed hydrocarbon fuel fire is a high temperature chemically reacting turbulent gas. The length and intensity of the fire is dependent upon the fuel supply, oxygen level and upon the heat available. These hydrocarbon fires are extremely high in soot concentration, and the flame temperature

is generally between 1500°-2000°F in the fire zone. Since the carbon or soot concentration is high it is assumed that the principle mechanism by which heat is transferred from a fire to an object engulfed in flames is by radiation. The test item is assumed to be completely engulfed in the fire with the dimensions of the fire being much greater than the dimensions of the test item. The character of the radiation is essentially that of a gray gas with effective emittance of 0.8 to 1.0. It is the soot concentration that gives the gas its high effective emissivity. Convection plays a secondary but important role in large fires. If the emissivity of the fire and the absorptivity of the item is assumed to be unity, than the average heat flux may be expressed as

$$q = \sigma(T_f - T_s)^4$$

where

q = the heat flux BTU/hr-ft²

σ = the Stephan-Boltzman constant 0.1713×10^{-8} BTU/hr-ft² °R⁴

T_f = the average temperature of the fire

T_s = the temperature of the outer surface of the case

Previous investigators (references 1 - 3) have characterized fires by reporting either an incident heat flux (based on $T_f^4 \gg T_s^4$) or a fire temperature. If one assumes the emissivity of the fire to be unity, then the incident flux, q, (in) is related to the fire temperatury by $q(in)=\sigma T_f^4$. Takata (reference 2) studied the frequency of incident fluxes in hydrocarbon fires of different sizes. The results of his work are shown in Table 1.

Table 1

Frequency of Specific Incident Heat Fluxes

Incident Heat Flux, BTU/Hr-Ft²	Frequency of Occurrence
25,000 - 30,000	0.08
30,000 - 35,000	0.12
35,000 - 40,000	0.18
40,000 - 45,000	0.21
45,000 - 50,000	0.29
50,000 - 55,000	0.12
25,000 - 55,000	1.00

Based on the work of Takata and other investigators, incident heat fluxes of 30,000 BTU/Hr-Ft² and 45,000 BTU/Hr-Ft² were selected

as being representative of liquid hydrocarbon fires. The fire temperatures corresponding to 30,000 and 45,000 BTU/Hr-Ft^2 are 863°C and 981°C respectively.

The Fuze M904E2 surface to be protected thermally is approximately 3" diameter by 3" long. The front of the fuze cannot be protected easily because of an arming vane which must turn freely. If we take the average flame temperature of the jet fuel fire as 1600°F nominal, the heat flux produced is approximately 36,000 BTU/Hr-Ft^2. If it is assumed that the fire completely surrounds the fuze then the area exposed to the radiative (90%) and convective (10%) heat flux is (π) 3 in x 3 in = 28.2 in^2 or $\frac{28.2}{144}$ = .195 Ft^2. Based on this area the heat flux to the fuze is 0.9 x .195 x 36,000 = 6300 BTU/Hr radiative and 0.1 x .195 x 36,000 = 700 BTU/Hr convective. If thermal protection is to be provided for 10 minutes then a total of approximately 1/6 of these values, 1050 BTU radiative heat and 116 BTU convective heat must be dissipated or otherwise prevented from reaching the fuze.

Since the majority of the heat involved is radiated, a radiation shield will eliminate a large amount of the heat input to the fuze. The total heat inputs to a fuze surface are tabulated on Table 2 based on the use of highly polished aluminum or gold.

Table 2

Effect of Radiant Heat Shield on Total Heat Transmitted to a 3" Diameter x 3" Long Fuze Surface

Characteristic	Shield Material Aluminum High Polish	 Gold High Polish
Emissivity	0.1	0.02
Radiative Heat in 10 min. (BTU)	105	35
Convective Heat in 10 min. (BTU)	116	116

Note that the heat input to the fuze with a radiative shield is 81-87% less than the 1166 BTU input if no shield is used and if the fuze is considered to have an emissivity of one. However, because of the cost involved in a radiation shield and the handling which these fuzes receive, this approach was rejected.

Another method of delaying the arrival of the cook-off temperature to the lead and booster explosive in the fuze is to provide an insulative foam layer on the surface of the fuze. A typical foam insulation is assumed to have a density of 4 lbs/ft^3, specific heat 0.3 BTU/lb °F and thermal conductivity of 0.017 BTU-ft/hr-ft^2 °F. Calculations have been made to estimate the thickness of insulative foam needed at various heat fluxes to reach 300°F in 10 minute explosure to the flux. The results of these calculations are shown in Figure 1. This type of an approach was abandoned because the thickness of insulation required would be unacceptable.

MATERIAL CONSIDERATION

It was decided to investigate fifteen insulation materials for the exterior cylindrical portion of the Fuze M904E2. This was done by a screening test on the basis of such factors as fire performance (conducted at the Ames Research Center and NOL), physical properties, cost considerations and the results of exposure to thermal shock and temperature and humidity cycling. Table 3 lists the fifteen (15) candidates and the source of finished sleeve, or in some cases, source of material from which sleeves were fabricated.

TABLE [illegible]

Candidate Materials

Candidate No.	Code Name	Description	Source
1	BC-62	Proprietary Intumescent Rubber	Goodyear Rubber Company 1144 E. Market St. Akron, Ohio
2	N-NOL-30[illegible]	Neoprene (MIL-R-[illegible] - Fabricated Parts)	[illegible]ckwell Rubber Company 111[illegible] Shackamaxon St. Philadelphia, Pa.
3	N-NOL-6[illegible]	Neoprene (MIL-R-6[illegible] Sheet)	Aberdeen Proving Ground Aberdeen, Maryland Sleeves fabricated by Ga[illegible] Corp., Aberdeen, Md.
4	N-NOL-[illegible]13A	Neoprene, Boric Acid, Phenolic	Uniroyal Rubber Company Mishawaka, Indiana
5	FM-30	Proprietary Filled Polyester	[illegible] Corporation Lowell, Massachusetts
6	P-NOL-[illegible]	Polysulfide Rubber (MIL-S-[illegible])	Products Res. & Chem. Co. [illegible]-41[illegible] Jersey Ave. Gloucester City, N.J.
7	P-NOL-FM	Polysulfide Rubber and [illegible]% Tris [illegible],3 Dibromopropyl Phosphate (Firemaster)	Products Res. & Chem. Co. Gloucester City, N.J. Michigan Chemical Co. [illegible]1 East Ohio Chicago, Illinois
8	PF-1	Proprietary Filled Polysulfide Epoxy	Universal Propulsion Co. [illegible]46 Riverside, California
9	E-NOL-6	Epoxy Adhesive Paste (WS-13045A) and 5% Phenolic Microballoons	Hysol Div. of Dexter Corp. Pittsburgh, California Union Carbide, Bound Brook, N.J.
10	UR-3800	Butadiene-Acrylonitrile Rubber Boric Acid, Phenolic (WS-[illegible])	Uniroyal Rubber Co. Mishawaka, Indiana B.F. Goodrich Aerospace 500 S. Main, Akron, Ohio
11	UR-624	Proprietary Polyurethane, Boric Acid, Phenolic	Uniroyal Rubber Company Mishawaka, Indiana
12	N-NOL-7	Neoprene and 10% Firemaster	Uniroyal Rubber Company Mishawaka, Indiana
13	TH-1	Proprietary Filled Epoxy with Microballoons	Thiokol Chemical Company Brigham City, Utah
14	UP-1	Proprietary Filled Polyester	Unique Products [illegible]4 Cyprus St. Santa Ana, California
15	PL-44	Proprietary	Insulation Systems Inc. 1[illegible] South Richey St. Santa Ana, California

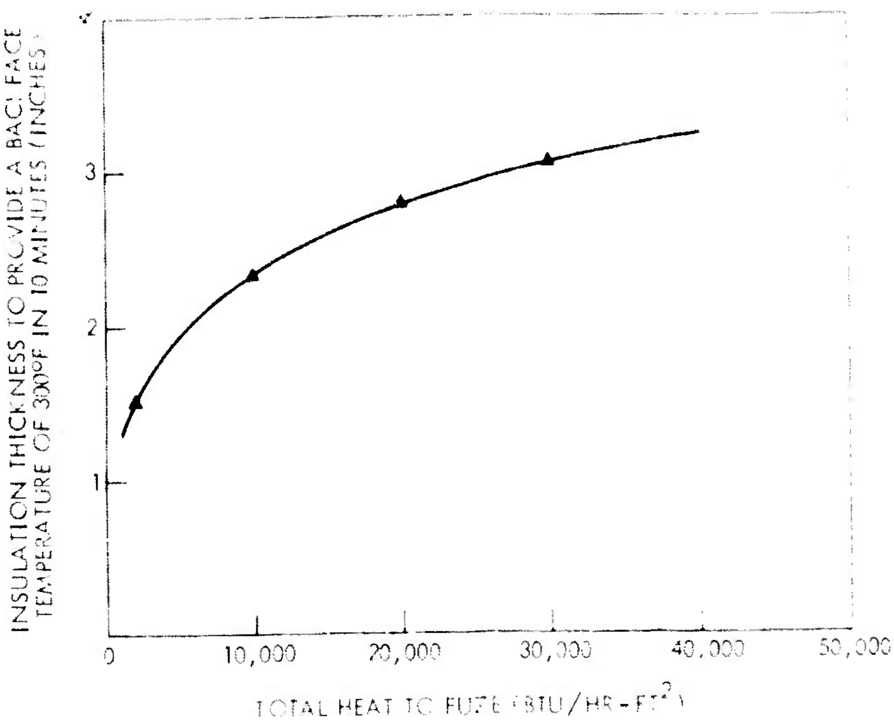

FIG. 1 FOAM INSULATION THICKNESS NEEDED FOR FUZE PROTECTION FOR 10 MINUTES

Specimen Preparation and Fire Tests at NOL

Two sizes of specimens were used for the candidate material study. Flat aluminum plates 9" x 5" x 1/8" were coated with ¼" of the test materials. These were instrumented with thermocouples and subjected to a Meeker burner flame. The heat flux was adjusted to 10 BTU/Sec-ft². A continuous recording was made of the temperatures associated with each test. A mask of rigid asbestos 12" x 12" x ½" with a 2.50" square in the center, was placed against the face of the sample assembly. The asbestos assembly equipped with the sample plate was then placed over the burner. The aluminum plate was outfitted with a thermocouple in order to measure the backface temperature. The backface thermocouple was kept in place by means of a fire brick which also acted as an insulator, allowing minimum heat losses.

Specimen Preparation and Fire Tests at NASA Ames

The Ames Test Facility utilized an oil burner which burned jet fuel at the rate of approximately 1½ gal/hr. The chamber was fire-brick lined, and the combustion products were exhausted out the top rear of the unit. For these tests the flow rate to the burner was adjusted to maintain 10 to 10.5 BTU/ft² sec (36,000 - 37,800 BTU/ft² hr) total heat flux. The temperature at the hot face of the sample was maintained at 1700°F minimum throughout the test. The samples used for this test were 2-7/8" x 2-7/8" x ¼" specimens. A schematic of the sample assembly is shown in Figure 2. The samples were backed with 1/8" thick 2024-T4 aluminum alloy, bonded to the surface with a high temperature epoxy. The back plate had a 1.25 in. diameter hole, to which was bonded a 1" diameter slug calorimeter of the same class and thickness. The aluminum back or supporting plate had a dual function. First it represented the thickness of the actual fuze skin, and second it acted as a supporting plate for the samples in the test apparatus and prevented any warping of the insulating sample during the test. The test samples were placed in a mask of asbestos 12" x 12" x ¼" thick with a 2-7/8" square cut in its center and then placed in the oil burner. The aluminum backface temperature was recorded continuously for the test duration.

Temperature and Temperature and Humidity Treatment

The temperature and humidity tests were employed to get preliminary information on the ability of the materials to withstand adverse climatic conditions of temperature and humidity. The total test is made up of two complete 14-day "JAN temperature and humidity cycles". The basic 14-day unit or "JAN temperature and Humidity cycle" consisted of cycling the samples nine times between the extremes of +160°F (95 percent RH) and -65°F with additional storage at +160°F (95 percent RH) and -80°F. The first step was to store the test item (2-7/8" x 2-7/8" x 1/8" aluminum plate with test insulator cemented on with epoxy cement) in a cabinet at -65°F

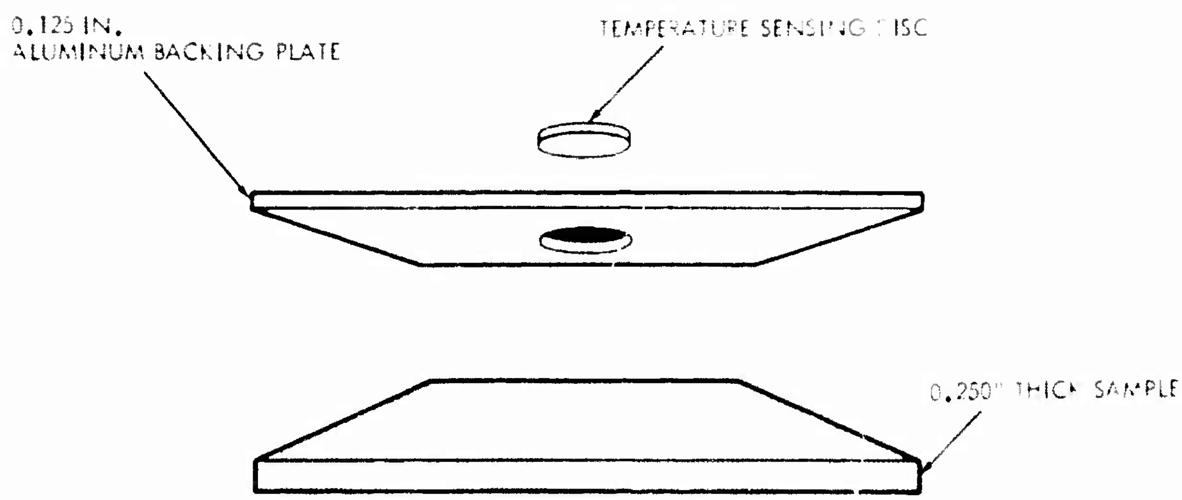

FIG. 2 SAMPLE PLATE ASSEMBLY

for two hours. The temperature was then raised to +160°F (95% RH) and the test item maintained at this temperature for 14 hours. The temperature was then lowered again to -65°F and the samples maintained at this temperature for two hours. The operations were repeated Monday to Friday. After raising the cabinet temperature to +160°F (95% RH) on Friday evening, these conditions were maintained until 0800 on the following Monday. At 0800 Monday, the sequence of operations was carried out again until Friday of the second week. On Friday of the second week the cabinet temperature was reduced to -60°F instead of -65°F and this temperature was maintained until the beginning of the third week. The second cycle then began. Two such cycles were applied in testing these insulators. In addition, samples were stored at -65°F for 28 days and also at 160°F for 28 days in order to determine which conditions were the most severe for the various samples. Hardness measurements were taken every week to determine any post-curing or degradation. Hardness measurements were made with the Shore Durometer Hardness Tester Type A-2. The samples were allowed to come to room temperature before the measurements were made. Samples 1, 2, 3, 4, 10, 11, 12 (refer to Table 3) (rubbery type sheet materials) were cemented to the aluminum plate by epoxy cement and allowed to cure overnight. All of the other plates were prepared by applying a mixed resin system to one surface of an aluminum plate with a spatula. The proper thickness was obtained by machining the finished samples whenever possible. Many of the mixed resin systems (samples No. 5, 6, 7, 8, 9, 13, 14 and 15 (Table 3)) were quite viscous and difficult to mix.

A single Chromel-Alumel thermocouple was attached to each specimen by means of aluminum backed tape and was held in place by means of a good insulator such as fire brick.

Results and Conclusion of Burn Tests

Prior to testing the specimens, the thickness of each of the insulating materials was determined in several locations especially in the center around the slug calorimeter.

The individual test specimens were than exposed to the flame with a heat flux of 10 to 10.6 BTU/ft² sec. Only the coated surface of the flat plate specimens were exposed to the flame. The fire temperature was 1750°F.

Time-temperature plots were recorded and exposure was terminated when the temperature reached 400°F. The test specimens were examined after exposure and photographs taken of some of the specimens after the test are shown in Figure 3.

After an induction period of approximately 35 seconds the time-temperature curves were essentially linear. Figure 4 is a typical time-temperature plot. Since different thicknesses were involved with each sample, the data were normalized to account for

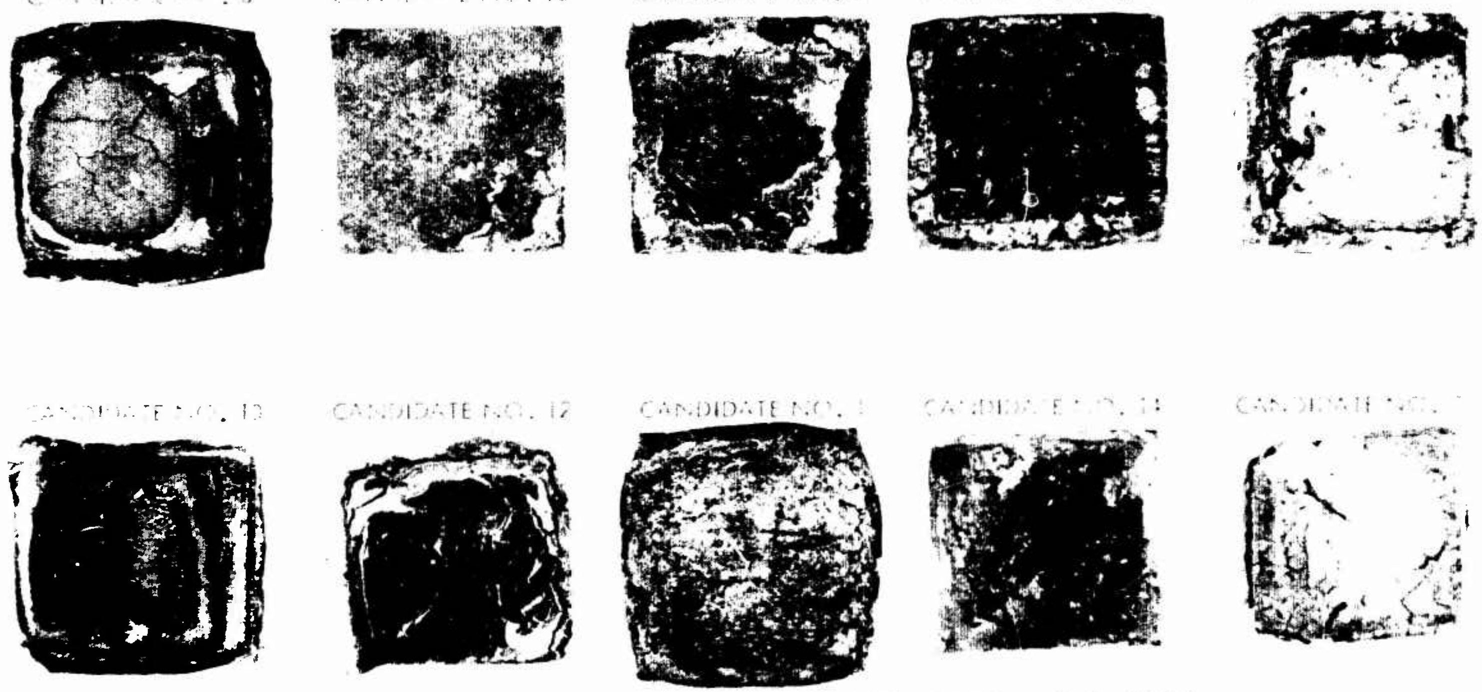

FIG. 3 PHOTOGRAPH OF SPECIMENS AFTER EXPOSURE TO FLAME OF [illegible]

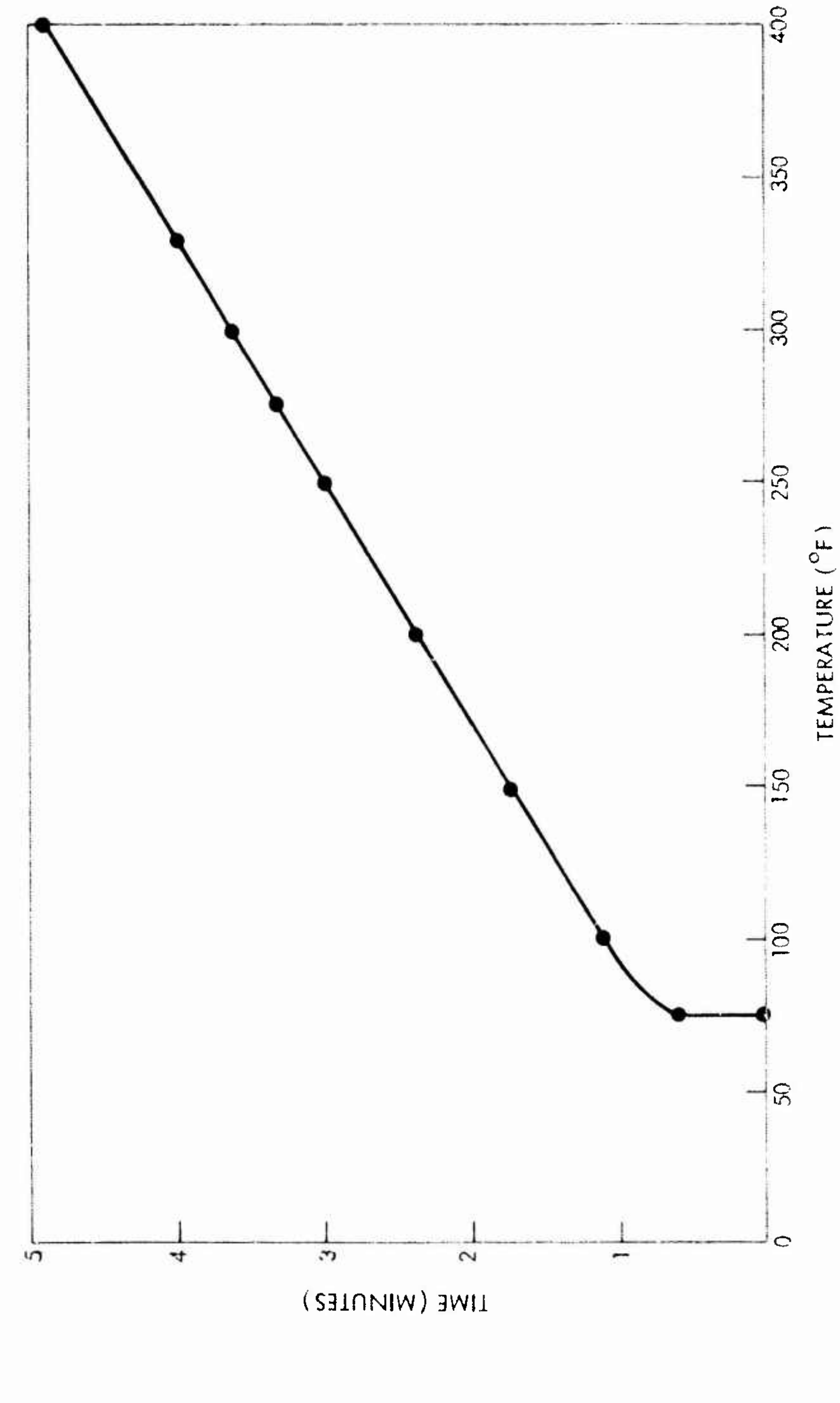

FIG. 4 TYPICAL TIME - TEMPERATURE PLOT OF BACKFACE TEMPERATURE ON EXPOSURE TO 1750°F FLAME

differences in thickness. Both the NASA burn test results and NOL burn test results are shown in Table 4. The thermal barriers are ranked in the order of their insulating properties in Table 5. From Table 5 it can be seen there is reasonable agreement from both types of tests. One of the candidates produced an outstanding firm and rigid char. Its lower ranking was believed to be due to a crack at the thermocouple position and points up a possible serious disadvantage of small scale tests of this nature. Small imperfections sometimes cause catastrophic failures, whereas, in actual large scale fire tests, the temperature effects of the crack are averaged over a large surface area.

After completion of the small scale fire tests, five candidate samples were discarded from the program as no longer promising. These candidate samples were No. 9, No. 15, No. 11, No. 6 and No. 2. The remainder of the samples were subjected to -65°F, -65°F to +160°F (95% RH) and +160°F with weekly withdrawls. Figures 5 through 14 are plots of Shore A Durometer hardness as a function of time for the three conditions of exposure. The change in hardness was measured since this characteristic is related to the change in crosslink density of a polymeric network. Tables 6 through 15 represent the times to reach 200°F, 400°F and the temperature at the end of 10 minutes after exposure to a Butane flame of 2000°F. The changes in fire protection were qualitatively followed in this manner. Table 16 includes various observations associated with the material treatment.

Figure 5 shows the effect of accelerated climatic conditions on the physical and mechanical properties of candidate No. 8 material, indicating that the material looses about 100% of its strength after 28 days of exposure in the JAN cycle changing from a rigid polymer to a soft putty like material. Table 6 indicates that the material also loses part of its thermal insulating properties when cycled between -65°F and +160°F. However, the insulating properties are still quite good (Table 6).

Candidate No. 1, intumescent Neoprene rubber, appears to possess good low and high temperature resistance. Figure 6 indicates no significant changes in crosslink density. Table 7 indicates no loss of fire protection after one month of storage at high and low temperatures.

Candidate No. 14 was affected by environmental storage. Table 8 indicates that the cycled conditions were the most severe. After 28 days in the JAN cycle, the material appeared to have lost part of its insulating properties (Table 8). Figure 7 indicates a degradation in crosslink density at +160°F and after JAN cycling. The material also cracked badly after 28 days of JAN cycling. It also appeared to have lost its adhesion to the aluminum substrate.

Candidate No. 12 was also affected by accelerated aging. Figure 8 shows that when the material was cycled depolymerization occurred. The rubber compound changed from a soft rubbery material

Table 4 - Results of Small Scale Burn Test at NASA and NOL

Candidate Number & Code Name	NASA Test Results: Thickness Inches	NASA Test Results: Time to 400°F in Sec.	NASA Test Results: Time to 400°F Thickness	NOL Test Results: Thickness Inches	NOL Test Results: Time to 400°F in Sec.	NOL Test Results: Time to 400°F Thickness
Control	0	50	--	0	60	--
No. 1 BC-62	0.178	260	1461	0.156	648	4154
No. 2 N-NOL-3065	0.179	180	1006	0.250	300	1200
No. 3 N-NOL-6855	0.300	330	1100	0.250	348	1392
No. 4 N-NOL-213A	0.173	245	1416	0.173	468	3744
No. 5 FM-30	0.254	280	1102	0.330	500	1515
No. 6 P-NOL-3	0.340	340	1000	0.330	444	1346
No. 7 P-NOL-FM	0.293	350	1194	0.330	576	1745
No. 8 PP-1	0.137	285	2080	0.125	588	4704
No. 9 E-NOL-6	0.306	195	637	0.281	268	953
No. 10 UR-3800	0.245	255	1040	0.250	636	2544
No. 11 UR-624	0.251	255	1016	0.250	300	1200
No. 12 N-NOL-7	0.115	180	1565	0.330	576	1745
No. 13 TH-1	0.195	245	1256	0.330	552	1673
No. 14 - UP-1	0.223	255	1143	0.375	660	1760
No. 15, PL-44	0.232	245	1056	0.375	564	1504

Table 5

Performance of Insulating Materials Ranked According to Their Insulating Properties

Candidate No.	NASA Ranking	Candidate No.	NOL Ranking
8	PF-1	[illegible]	PF-1
12	N-NOL-[illegible]	1	BC-[illegible]
1	BC-6[illegible]	4	N-NOL-[illegible]3A
4	N-NOL-[illegible]3A	10	UR-[illegible]
13	TH-1	14	UP-1
7	P-NOL-FM	7	P-NOL-FM
14	UP-1	12	N-NOL-[illegible]
10	UR-3500	13	TH-1
11	UR-624	5	FM-30
5	FM-30	15	PL-44
3	N-NOL-6855	3	N-NOL-6855
15	PL-44	6	P-NOL-3
2	N-NOL-3065	11	UR-624
6	P-NOL-3	2	N-NOL-3065
9	E-NOL-6	9	E-NOL-6

Table 6

Effect of Accelerated Climatic Conditioning on Fire Retardant Properties of PF-1 (Candidate No. 8)

Environment	Thickness Inches	Storage Time (weeks)	$t_{200°F}$ Minutes	$t_{400°F}$ Minutes	$T_{10\ Minutes}$ °F
Control	.194	1	6.4	>10	290
	.183	2	7.6	>10	245
-65° F	.189	1	6.2	>10	245
"	.182	2	[illegible].4	>10	245
"	.182	3	5.0	>10	335
-65° F - 160° F	.211	1	6.0	>10	270
" "	.189	2	6.4	>10	310
" "	.202	3	2.2	9.4	420
160° F	.195	1	6.8	>10	245
"	.201	2	5.4	>10	245
"	.211	3	3.4	>10	290

Table [illegible]

Effect of Accelerated Climatic Conditioning on Fire Retardant Properties of BC-62 (Candidate No. 1)

Environment	Thickness Inches	Storage Time (weeks)	$t_{200°F}$ Minutes	$t_{400°F}$ Minutes	$T_{10\ Minutes}$ °F
Control	.273	1	[illegible].6	>1[illegible]	[illegible]
	.283	2	[illegible]	>1[illegible]	[illegible]
	.283	4	[illegible]	>10	[illegible]
-[illegible]°F	.271	1	[illegible].4	>10	[illegible]
"	.271	2	[illegible]	>10	[illegible]
"	.27[illegible]	3	>10	>10	150
"	.28[illegible]	4	[illegible]	>10	[illegible]45
-[illegible]°F - 160°F	.28[illegible]	1	[illegible]	>10	[illegible]10
" "	.280	3	[illegible]	>10	200
" "	.289	4	>10	>10	18[illegible]
1[illegible]0°F	.269	1	[illegible]	>1[illegible]	[illegible]10
"	.300	[illegible]	[illegible]	>1[illegible]	[illegible]20
"	.301	3	[illegible]	>1[illegible]	[illegible]20
"	.30[illegible]	4	[illegible]	>1[illegible]	[illegible]50

Table 8

Effect of Accelerated Climatic Conditioning on Fire Retardant Properties of UP-1 (Candidate No. 14)

Environment	Thickness Inches	Storage Time (weeks)	$t_{200°F}$ Minutes	$t_{400°F}$ Minutes	T_{10} Minutes °F
Control	.253	2	2.4	7.2	555
"	.223	3	3.0	7.3	535
"	.228	4	2.2	6.4	655
-65° F	.266	1	3.4	8.3	535
"	.241	2	3.4	8.8	445
"	.261	3	3.9	>10	380
"	.263	4	2.6	7.2	750
-65° F - 160° F	.249	1	3.3	6.9	640
" "	.248	2	3.6	6.8	635
" "	.248	3	3.0	5.9	750*
" "	.251	4	2.0	3.9	---*
160° F	.239	2	1.2	4.5	730
"	.242	3	2.0	4.2	730
"	.273	4	1.2	2.4	---*

*Sample Aflame

Table [illegible]

Effect of Accelerated Climatic Conditioning on Fire Retardant Properties
N-NOL-7 (Candidate No. 1[illegible])

Environment	Thickness Inches	Storage Time (weeks)	$t_{200°F}$ Minutes	$t_{400°F}$ Minutes	$T_{10\ Minutes}$ °F
Control	.181	2	2.7	4.[illegible]	7[illegible]0
	.149	2	[illegible].1	[illegible]	---
	.157	4	[illegible]	[illegible].4	---
-65°F	.1[illegible]	1	[illegible].4	3.	---*
	.164	[illegible]	2.4	4.[illegible]	---
	.177	[illegible]	3.6	4.[illegible]	---
	.177	4	[illegible]	[illegible].7	---
-65°F - 160°F	.144	1	1.[illegible]	[illegible]	---
	.153	[illegible]	1.[illegible]	[illegible]	---
	.167	4	1.[illegible]	[illegible]	---
160°F	.171	1	1.[illegible]	4.1	[illegible]75
	.157	[illegible]	1.[illegible]	[illegible].7	---
	.1[illegible]	[illegible]	1.[illegible]	[illegible]	---

*Thermocouple came loose, sample sagged in center.

Table 1[illegible]

Effect of Accelerated Climatic Conditioning on Fire Retardant Properties
N-NOL-21[illegible]-A (Candidate No. 4)

Environment	Thickness Inches	Storage Time (weeks)	[illegible]00°F Minutes	[illegible]00°F Minutes	T 10 Minutes °F
Control	.[illegible]	1	[illegible]	[illegible].1	[illegible]
	.220	[illegible]	[illegible]	[illegible]	51[illegible]
	.234	[illegible]	[illegible]	[illegible]	[illegible]
-[illegible]°F	.227	1	[illegible]	[illegible]	[illegible]
	.216	[illegible]	7.[illegible]	>10	[illegible]
	.242	[illegible]	[illegible]	[illegible]	[illegible]15
	.222	4	[illegible].1	[illegible]	[illegible]15
-65°F - 160°F	.227	1	2.6	5.6	1005
	.246	[illegible]	3.0	[illegible].2	555
	.247	3	3.3	[illegible].7	475
	.233	4	2.[illegible]	3.6	103[illegible]
160°F	.227	1	3.[illegible]	[illegible]	445
	.220	2	2.4	[illegible]	410
	.234	3	[illegible].4	>10	310
	.20[illegible]	4	1.[illegible]	[illegible]	[illegible]

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Table 10

Effect of Accelerated Climatic Conditioning on Fire Retardant Properties of P-NOL-FM (Candidate No. [illegible])

Environment	Thickness Inches	Storage Time (weeks)	$t_{200°F}$ Minutes	$t_{400°F}$ Minutes	$T_{10\ Minutes}$ °F
Control	.265	1	4.[illegible]	>10	310
	.259	2	3.8	>10	370
	.259	3	3.[illegible]	>10	380
-65°F	.261	2	4.[illegible]	>10	335
	.269	3	4.0	9.[illegible]	445
	.269	4	3.4	[illegible].2	470
-65°F - 160°F	.284	1	3.[illegible]	7.[illegible]	500
	.270	2	4.0	[illegible].0	460
	.279	3	3.4	[illegible].6	490
	.260	4	1.[illegible]	4.3	875
160°F	.282	1	4.2	>10	355
	.271	2	3.0	[illegible]	450
	.28[illegible]	3	2.6	[illegible]	640
	.271	4	1.[illegible]	4.5	815

Table 13

Effect of Accelerated Climatic Conditioning on Fire Retardant Properties of TH-1 (Candidate No. 13)

Environment	Thickness Inches	Storage Time (weeks)	$t_{200°F}$ Minutes	$t_{400°F}$ Minutes	$T_{10\ Minutes}$ °F
Control	.353	2	4.2	>10	3[illegible]0
	.235	3	2.[illegible]	[illegible].4	>[illegible]60
	.294	4	0.[illegible]	3.[illegible]	11[illegible]
-65°F	.217	1	2.[illegible]	[illegible].3	>[illegible]00
	.24[illegible]	2	3.0	[illegible].3	[illegible]40
	.231	3	3.3	[illegible]	[illegible]
	.311	4	[illegible]	[illegible]	>104[illegible]*
-65°F - 160°F	.22[illegible]	1	3.1	[illegible]	>1024
	.256	2	3.1	7.[illegible]	560
	.25[illegible]	3	3.6	[illegible].0	>790
160°F	.224	1	1.[illegible]	[illegible].3	>1070
	.261	2	[illegible].4	[illegible].[illegible]	[illegible]
	.37[illegible]	3	[illegible]	>10	[illegible]

* Sample Aflame

Table 14

Effect of Accelerated Climatic Conditioning on Fire Retardant Properties of FM-30 (Candidate No. 5)

Environment	Thickness Inches	Storage Time (weeks)	$t_{200°F}$ Minutes	$t_{400°F}$ Minutes	$T_{10 \text{ Minutes}}$ °F
Control	.244	2	2.8	7.6	510
	.239	3	2.4	6.0	600
-65° F	.273	1	4.0	7.8	510
	.259	2	3.6	8.8	435
	.233	3	3.1	5.9	575
-65° F - 160° F	.274	1	4.4	10.0	400
	.279	2	5.8	9.8	420
	.236	3	5.6	>10	355
160° F	.260	1	3.5	10.0	400
	.241	2	2.3	6.4	530
	.240	3	2.3	5.5	660

Table 15

Effect of Accelerated Climatic Conditioning on Fire Retardant Properties of MIL-R-6855 Neoprene (Candidate No. 3)

Environment	Thickness Inches	Storage Time (weeks)	$t_{200°F}$ Minutes	$t_{400°F}$ Minutes	$T_{10\ Minutes}$ °F
Control	.250	2	1.5	4.0	590
	.261	3	1.7	5.4	535
	.261	4	1.9	5.8	555
-65°F	.259	1	1.5	5.2	535
	.272	2	2.0	5.4	545
	.261	3	1.8	5.4	535
	.250	4	1.5	4.4	540
-65°F - 160°F	.260	1	1.0	5.6	555
	.296	2	2.2	5.8	555
	.258	3	1.8	5.3	665*
	.256	4	2.0	Fuel shut off after 2.5 min; Sample was aflame.	
160°F	.271	1	1.7	[illegible]	450
	.273	2	1.4	4.6	550
	.272	3	1.7	5.4	470
	.251	4	1.6	[illegible]	450

* Material fell apart in sheets.

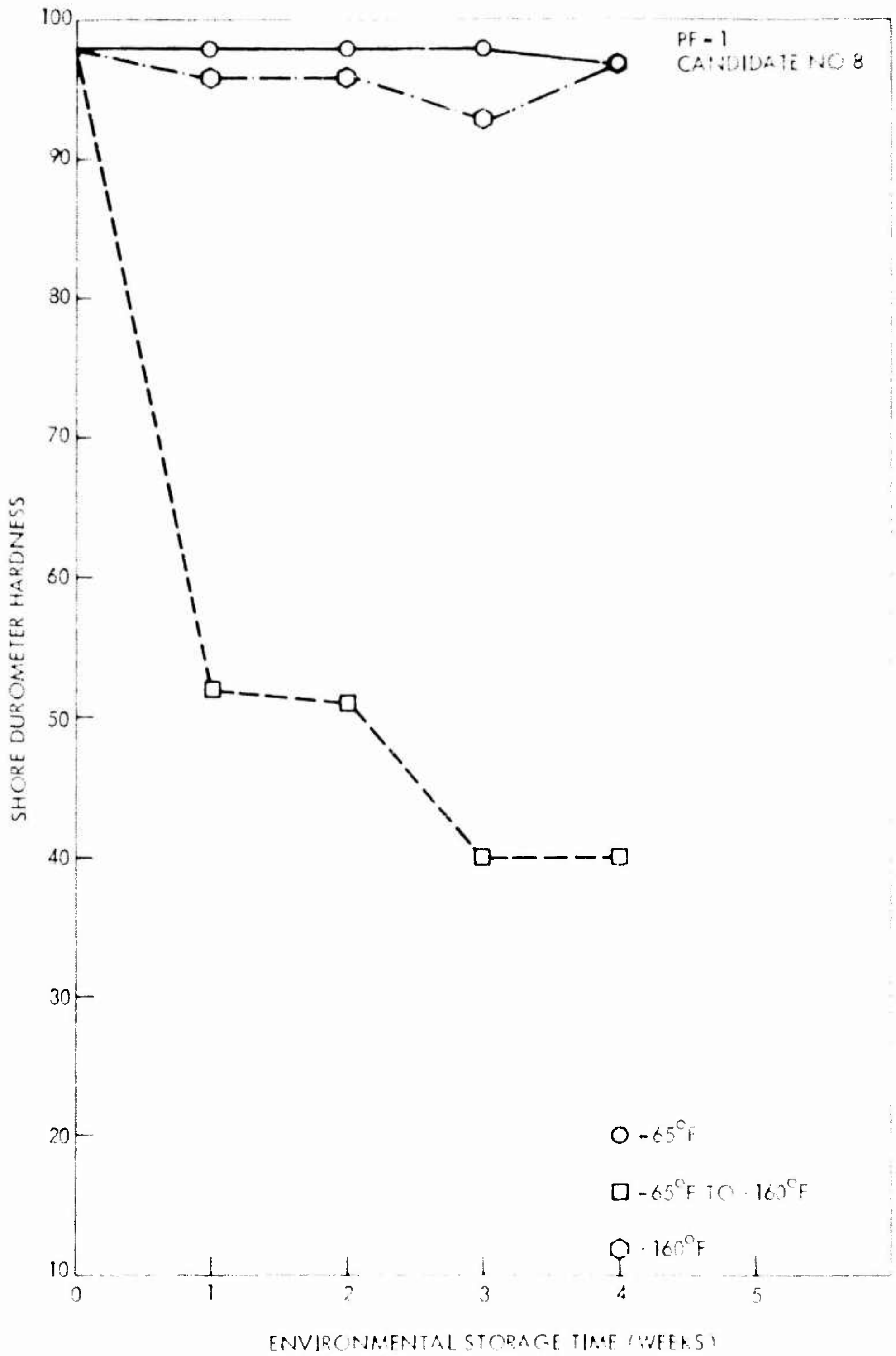


FIG. 5 SHORE A DUROMETER HARDNESS VS TIME
FOR THESE TEMPERATURE EXPOSURES

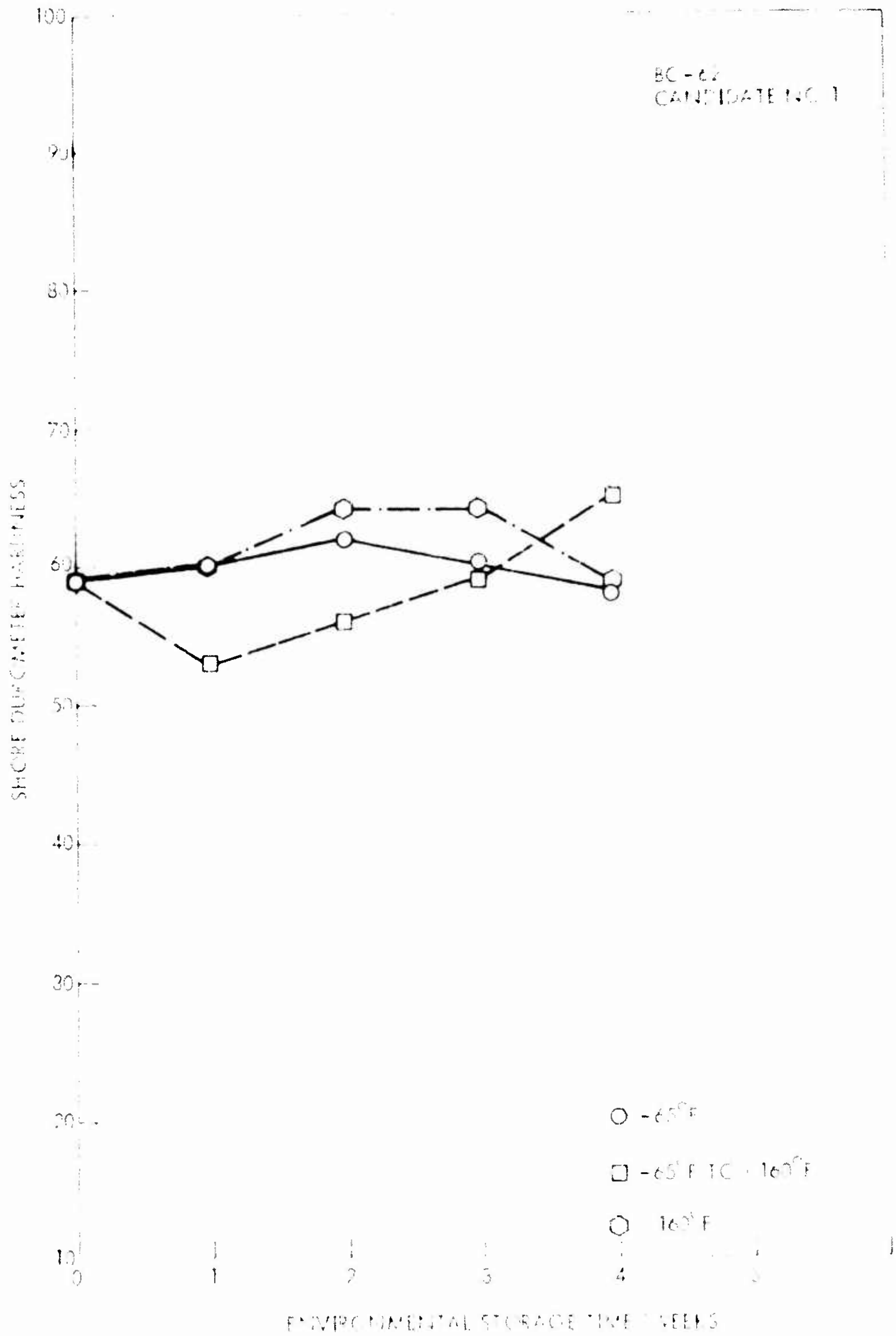


FIG. 6 SHORE A DUROMETER HARDNESS VS TIME FOR THESE TEMPERATURE

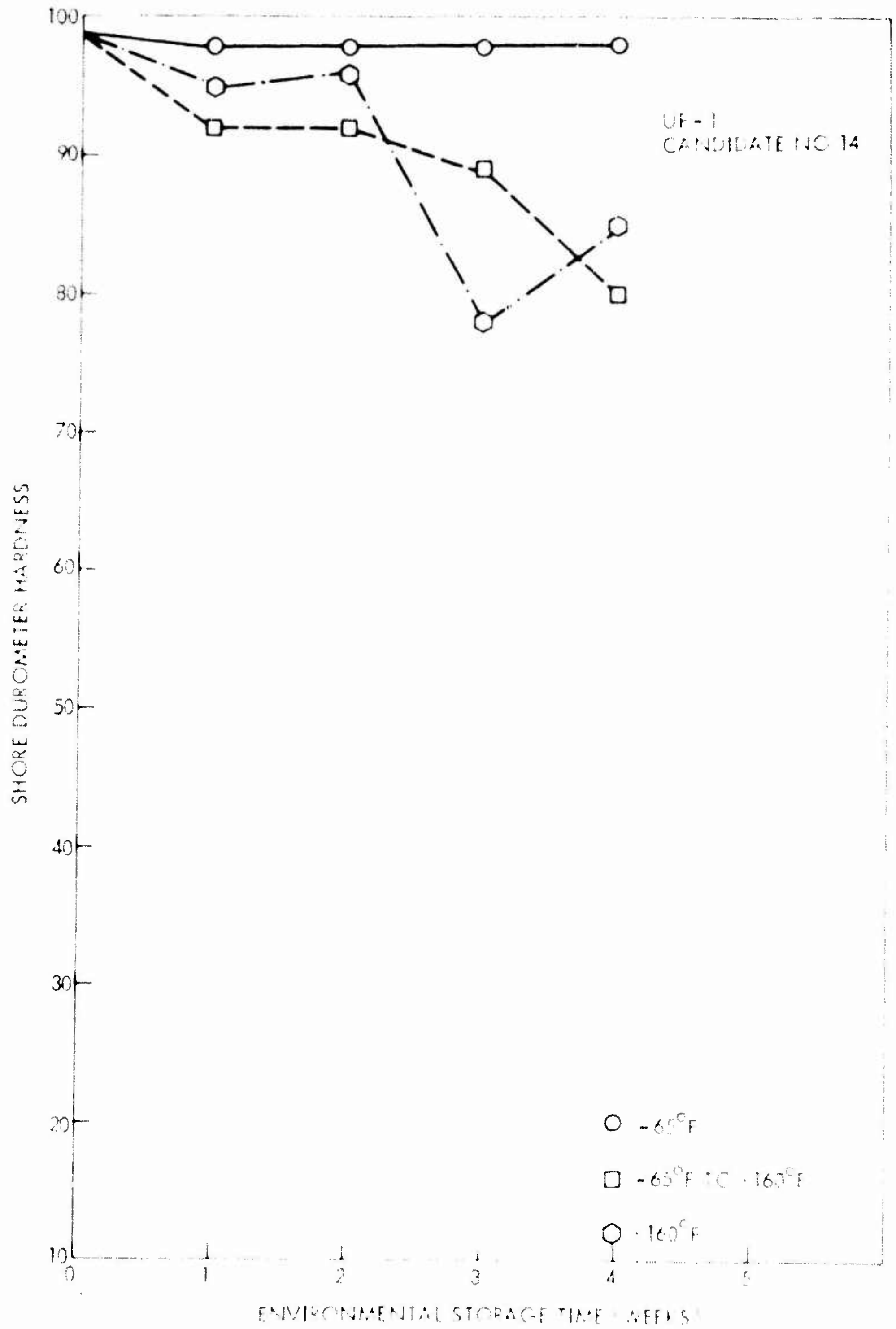


FIG. 7 SHORE A DUROMETER HARDNESS VS TIME FOR THESE TEMPERATURE EXPOSURES

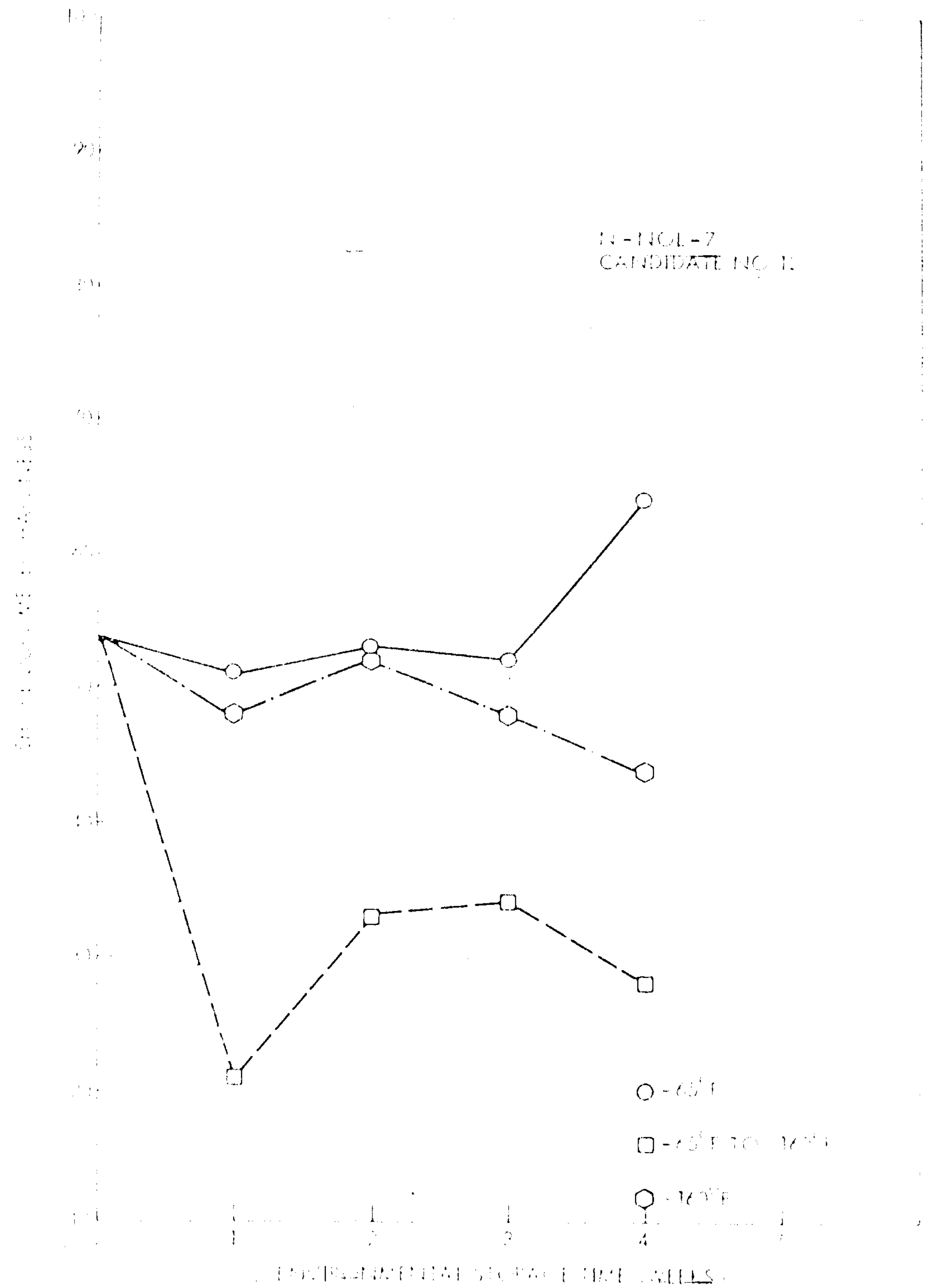


FIG. 8 SHORE A DUROMETER HARDNESS VS TIME FOR THREE TEMPERATURE EXPOSURES

to a jell. The sample also discolored, changing from an off white color to a reddish brown. The fire retardancy of the material, shown in Table 9 does not appear to be affected by the environmental treatment. On a close examination of the rubber it appears as though the tris 2,3 dibromopropyl phosphate was not compatible with the rubber stock.

Figure 9 and Table 10 indicate that the Candidate No. 4 was affected by both the high temperature and low temperature storage conditions. The material appears to show a marked degradation in physical properties and thermal protection after low temperature storage, and exposure to the 28 day JAN cycle.

Figure 10 indicates the changes in mechanical properties and thermal protection of Candidate No. 10. The rubber appears to be post curing at the elevated temperature, the performance in a fire is shown on Table 11.

The physical properties of Candidate No. 7 do not appear to be affected by the accelerated temperatures (Figure 11). The material was relatively soft at the onset, and appears to assume a permanent set on aging at ±160°F. Table 12 indicates the material loses its intumescent character at 160°F.

The physical properties of Candidate No. 13 is shown in Figure 12; it was relatively unaffected by the storage conditions. The material, however, was extremely brittle and had poor impact resistance. The thermal properties were extremely poor and are shown in Table 13.

Figure 13 and Table 14 indicate Candidate No. 5 was somewhat affected by high temperature storage. Shrinkage/expansion characteristics appeared to be a problem area (Table 16).

Candidate No. 3 was relatively insensitive to the storage conditions at high and low temperatures as shown in Figure 14 and Table 15. The sample burned quite vigorously when the burner was removed from the sample.

Candidate No. 13 was eliminated on the basis that it would be incapable of withstanding the treatment it would experience in the Fleet. Candidate No. 3 was also eliminated because of its flammability.

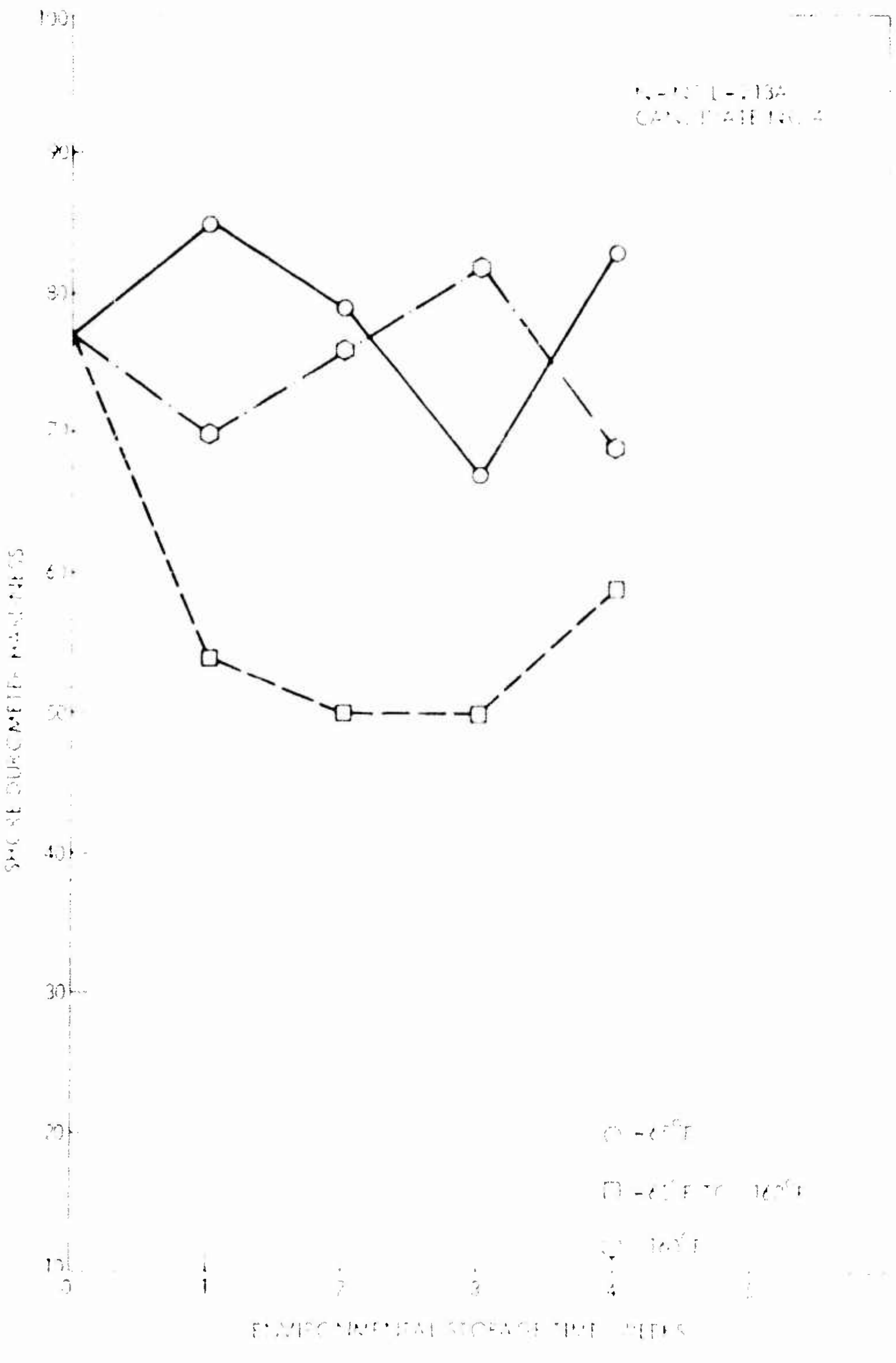
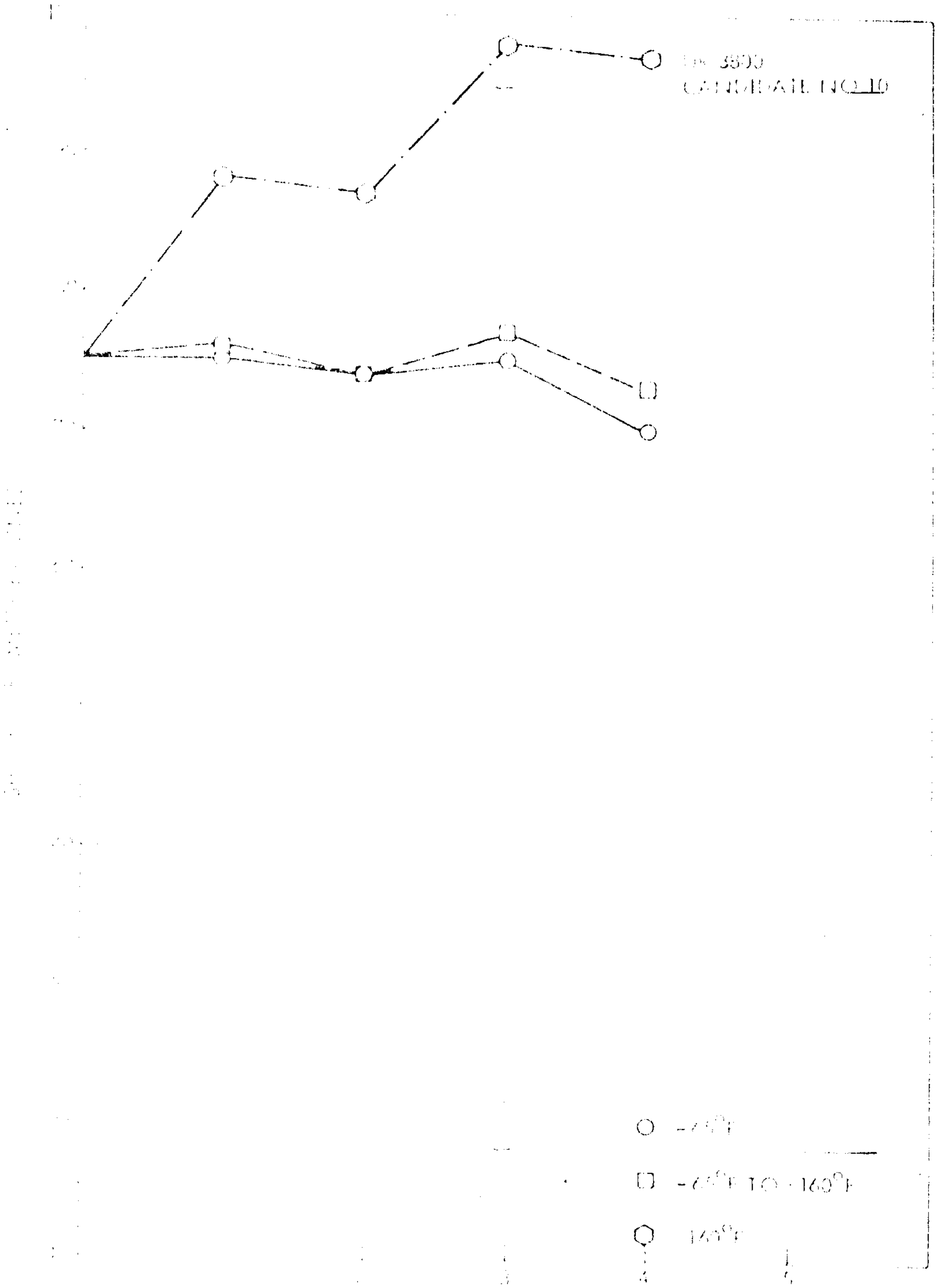


FIG. [illegible] SHORE A DUROMETER HARDNESS VS TIME
FOR THREE TEMPERATURE EXPOSURES



STORAGE TIME (WEEKS)

HARDNESS VS TIME
TEMPERATURE EXPOSURES

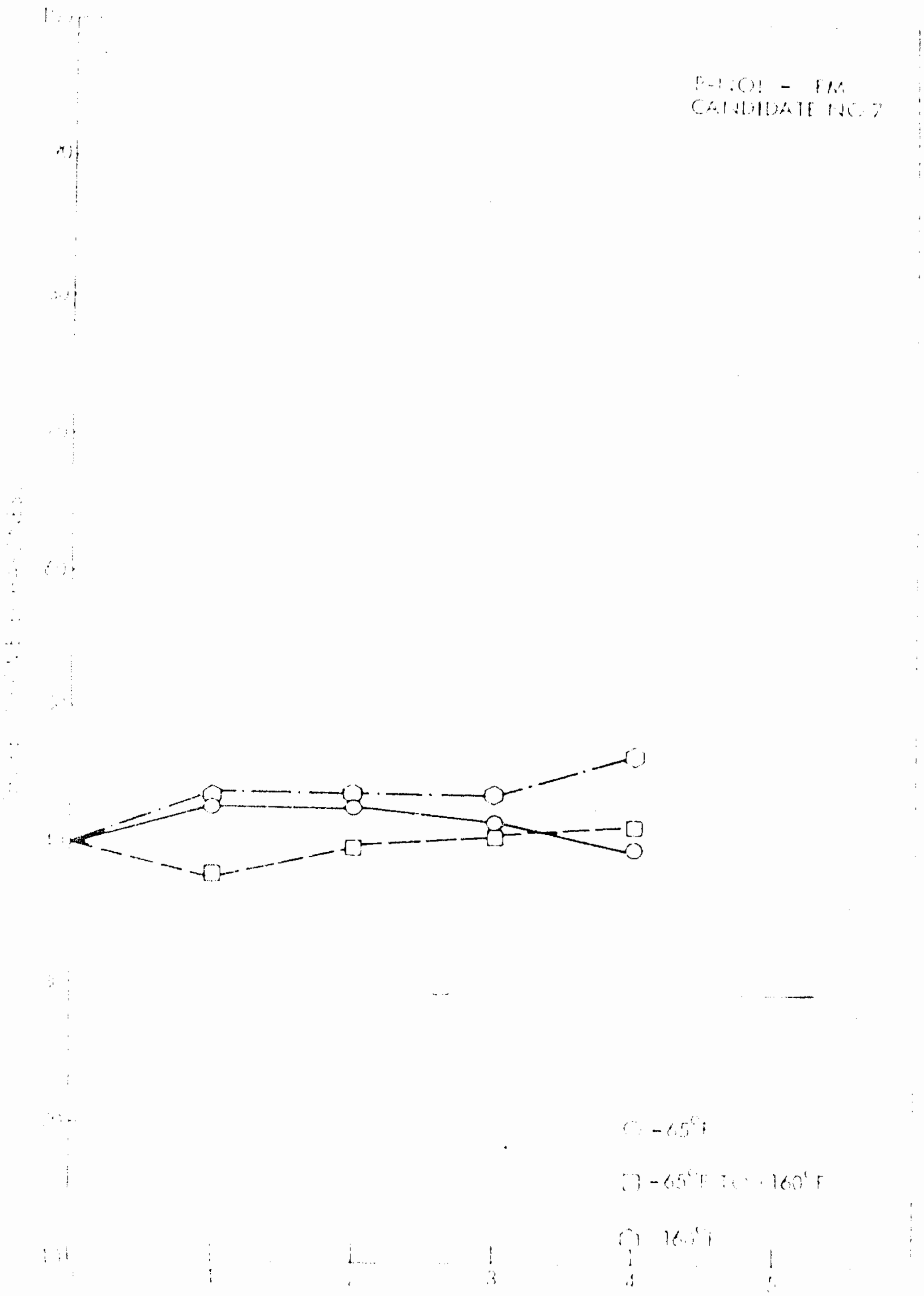


FIG. 11 SHORE A DUROMETER HARDNESS VS TIME FOR THREE TEMPERATURE EXPOSURES

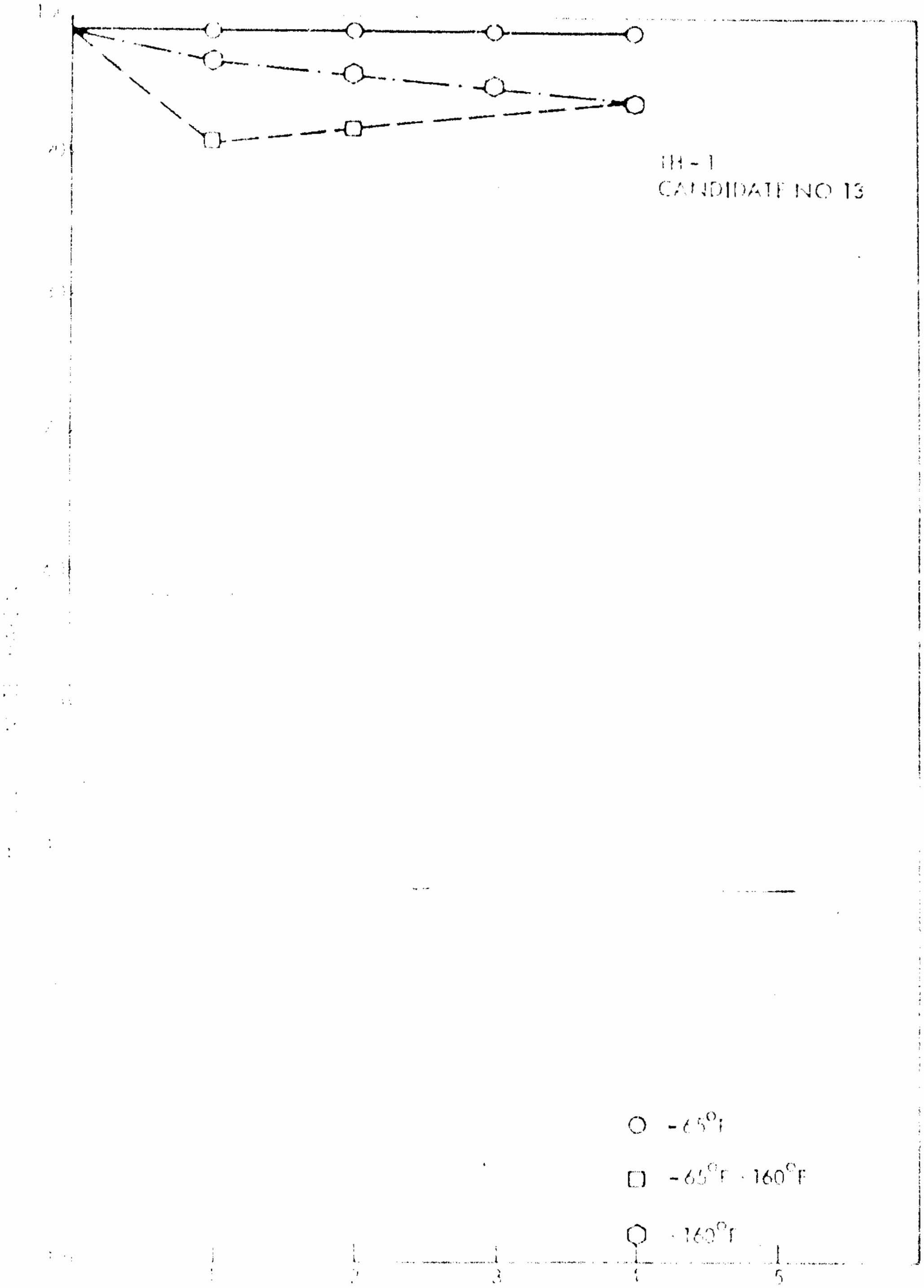


FIG. [illegible] SHORE A DUROMETER HARDNESS VS TIME FOR THREE TEMPERATURE EXPOSURES

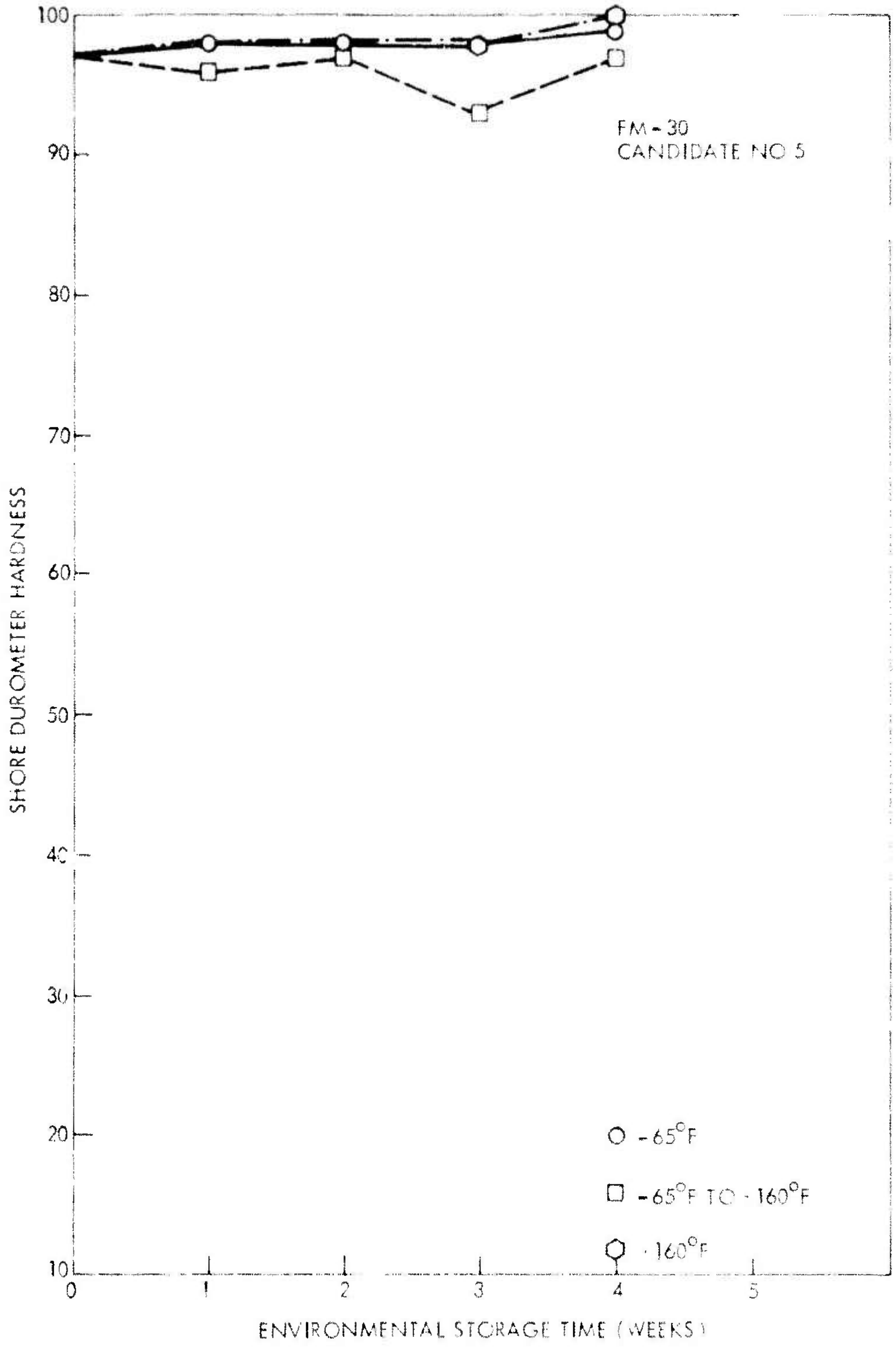


FIG. 13 SHORE A DUROMETER HARDNESS VS TIME FOR THESE TEMPERATURE EXPOSURES

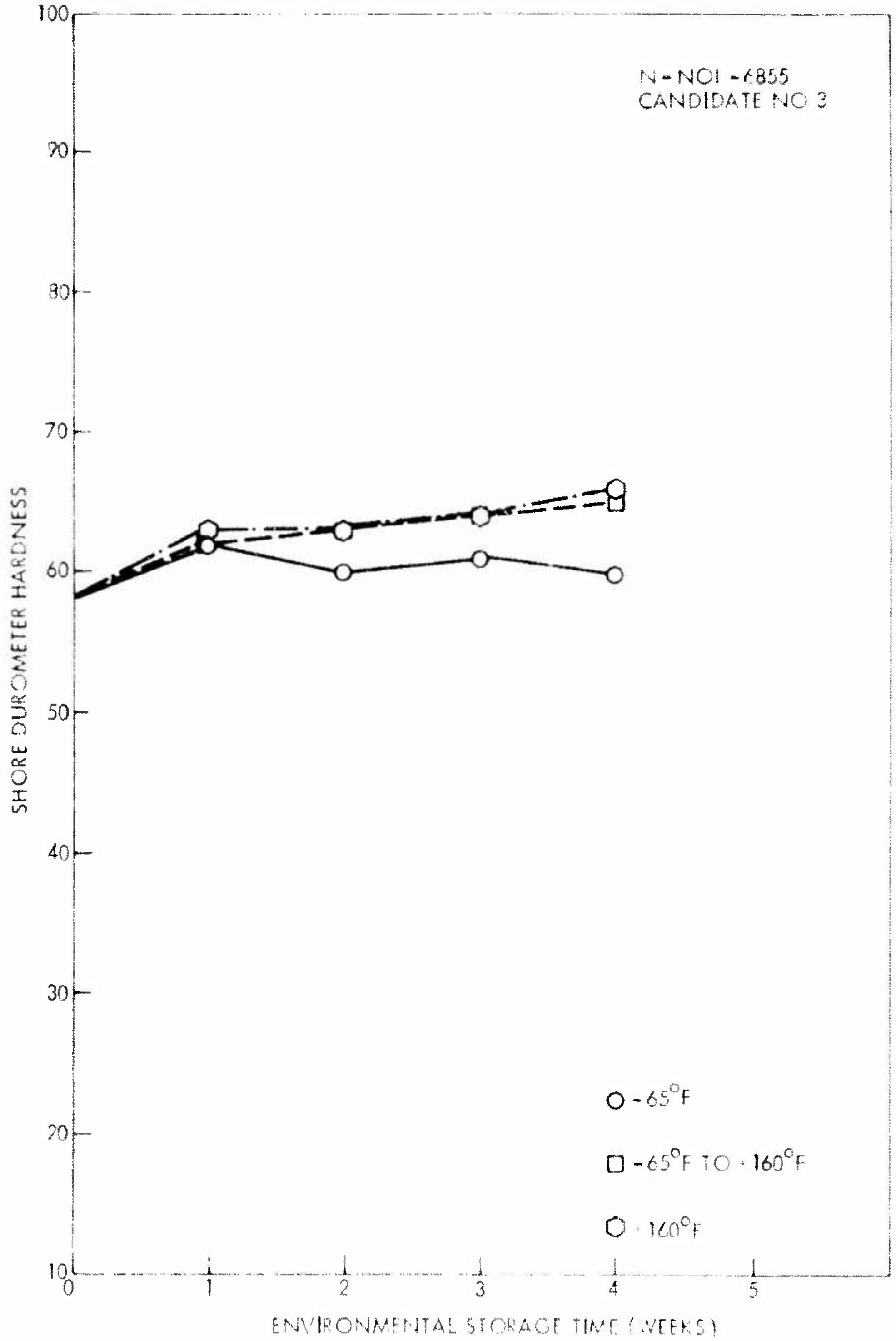


FIG. 14 SHORE A DUROMETER HARDNESS VS TIME FOR THESE TEMPERATURE EXPOSURES

Table 16

Summary of Effects of Climatic Conditioning of Candidate Materials

Material	Results
PF-1 Candidate No. 8	Changed in hardness--became soft. Marked degradation in physical properties. Lost some thermal properties.
BC-62 Candidate No. 1	No noticeable change.
UP-1 Candidate No. 14	Material warped at high temperature. On burning it pulled away from metal. At JAN cycle, thermal properties reduced and cracking occurred.
N-NOL-7 Candidate No. 12	Tris 2,3 DiBromopropyl Phosphate not compatible with Neoprene--became soft and mushy. Lost intumescence.
N-NOL-213A Candidate No. 4	Lost its fire protection and physical characteristics.
P-NOL-FM Candidate No. 7	Lost its intumescence at 160°F.
UR-3800 - WS 8939 Candidate No. 10	Post cured--properties improved with age. Produced outstanding char.
Neoprene MIL-R-6855 Candidate No. 3	No noticeable change.
Candidate No. 13	Material very brittle; questionable handling ruggedness.
Candidate No. 5	Lost some of its thermal properties at high temperature storage. Shrinkage/expansion characteristics were noted as possible problem area.

FIELD TEST PROGRAM

Concurrent with the laboratory program a field test program was planned and begun. Sleeves were fabricated and placed on M904E2 Fuzes. These were equipped with thermocouples, assembled to Mk 82 bombs and fire tested at White Sands Missile Range, New Mexico.

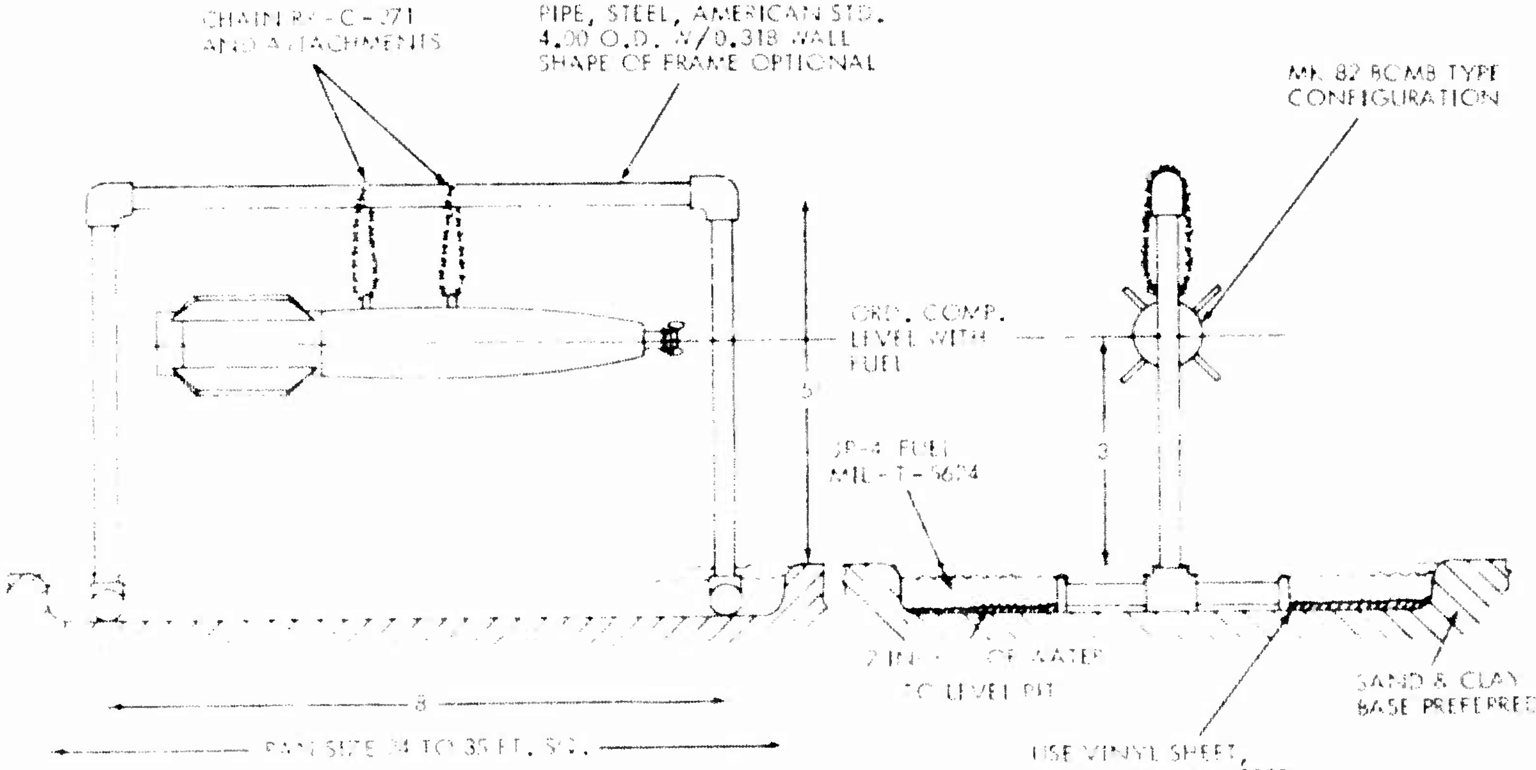
FAST COOK-OFF TEST ARRANGEMENT

Flame envelopment tests were performed by suspending the test item approximately 36" from the surface of 2800 gallons of JP-4 fuel. A 35' x 35' x 1' enclosure (pit) was constructed from sand and polyethylene sheet. The pit was located in an excavation 55" x 55" x 10" deep in order to minimize the effects of wind currents. The pit contained the fuel with two inches of water beneath the fuel to provide a level surface. The fuel was ignited with four thermite grenades modified with electric squibs. These were placed in four locations so as to initiate burning over the entire fuel surface, as rapidly as possible. The fire tests were conducted when the wind velocity was five knots or less, to ensure complete engulfment of the test item. Generally, the wind velocity at ground level was approximately twice as high as in the pit. Schematics of the field test arrangement are shown in Figures 15a and 15b. The instrumentation trailer was housed in an earth barricade to protect the occupants and instruments during the test. A trench 800 feet long x 1 foot deep x 1 foot wide was dug, in order to house the cables. After placement of the cables they were then covered with sand. A smaller earth barricade of 4' x 4' x 4' was dug approximately 50 feet from the burn pits in order to house the reference junction and to protect it from the intense heat. A preliminary specification for fast cook-off test of the Mk 80 series of low drag bombs is contained in Appendix C.

INSTRUMENTATION

A Vidar Data Acquisition System was used to measure the thermocouple data. This equipment is capable of scanning up to 1000-three wire guarded input channels and recording on paper tape. Approximately half-way during the program a magnetic tape recording capability was added which simplified the data reduction process. The system measured d.c. voltage between one microvolt and 300 millivolts which could be translated to a temperature range between -30°F and 3000°F. These modes and ranges of measurement were remotely selected and were programmed in blocks of 10 for easy insertion into the computer. The usefulness of this system is its high degree of noise immunity from both common and normal mode interference. The system normally scanned at the rate of 5 pts/sec although faster scanning rates were sometimes used. Twenty-eight gauge chromel-alumel thermocouple wire was used to instrument the test item, internally and externally. The external thermocouples were used to measure the fire temperature and were located symmetrically around the test item. Ice was used as the reference junction. Color motion picture cameras were used to cover each test and were located 1500 feet from the test. Normal frame rates of 24 fps were used. Still camera coverage was employed for documentary purposes. The test firings were viewed on closed circuit television and a video tape recording was made of each shot.

The capability to record the magnitude of pressure resulting from a bomb detonation was afforded by the use of Kytrex pressure transducers. Since the detonation of an explosive in air causes



NOTE: THE STANDS MAY BE PROTECTED WITH ASBESTOS CLOTH AND COVERED WITH 15 MILS OF STEEL FOR LONGER LIFE.

FIG. 15b SCHEMATIC OF FIELD TEST ARRANGEMENT

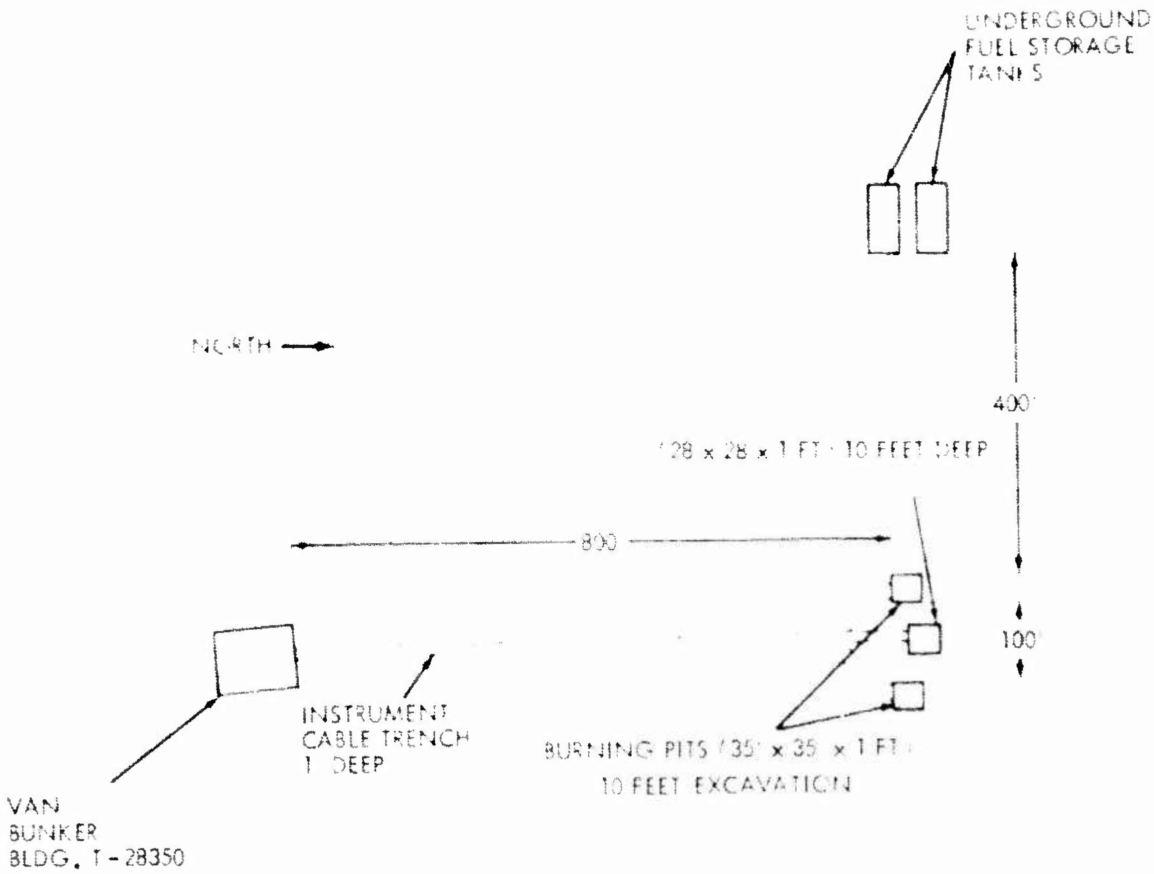


FIG. 15b TEST SITE LAYOUT

a relatively large amount of energy to be released in a short time, the shock wave starts with an initial high pressure near the explosive and eventually decays to a sound wave at some distance from the charge. The Bytrex transducer utilizes semi-conductor strain gages as the sensor. The gages are bonded to a force member which is attached to the center of a pressure responsive diaphragm. When the diaphragm is subjected to pressure, the force member is compressed. This compression induces a strain and changes the electrical resistance of the strain gages. The strain gages are connected to form a wheatstone bridge. When excited with a constant voltage, the change in resistance of the gage causes an unbalance in the wheatstone bridge and produces a voltage proportional to the applied pressure.

The signal conditioning equipment consists of two separate components. Transducer excitation was provided by a well regulated power supply capable of providing 0-30 volts d.c., when operated in the constant voltage mode, and 0 to 100 milliamps when operated in the constant current mode. The second signal conditioning component is provided for bridge balancing and shunt calibration of the transducer. The electrical calibrations were achieved by shunting one arm of the wheatstone bridge with a pre-determined resistance and measuring the voltage produced by the resulting bridge unbalance. D.C. amplifiers were used to increase the transducer output to the level required by the tape recorder FM record amplifier for full scale calibration. The amplifiers were differential amplifiers and had continuously variable gain from 1 to 1000 and a maximum output of 10 volts at 100 milliamps. The upper band pass of the amplifiers was 100 KHz.

Standard commercially available magnetic tape was used to record data on all tests. The tape recorders were supplied by the White Sands Missile Range. The recorders were used in the 20 KHz mode and all data was taken at a tape speed of 60 inches per second. The instrumentation is illustrated in block form in Figure 16.

A pin switch control circuit was set up and used in this program to establish the origin of any detonation or deflagration occurring in the cook-off of a Mk 82 bomb. Thermocouple wire was used as the sensing element. When a detonation or deflagration occurred, a switch was closed discharging a capacitor and triggering an oscilloscope equipped with a polaroid camera. The signal was also recorded on a tape recorder. By judiciously placing the probes at various positions in a Mk 82 bomb it was possible to ascertain the origin of the detonation wave. A complete description of the pin probe circuit is shown in Appendix A.

HARDWARE DESCRIPTION

The Fuze M904E2 is the most extensively used fuze in the Mk 80 series of bombs. Preliminary test data from the Naval Weapons Laboratory, Dahlgren, Virginia, indicated that the Fuze M904E2 was

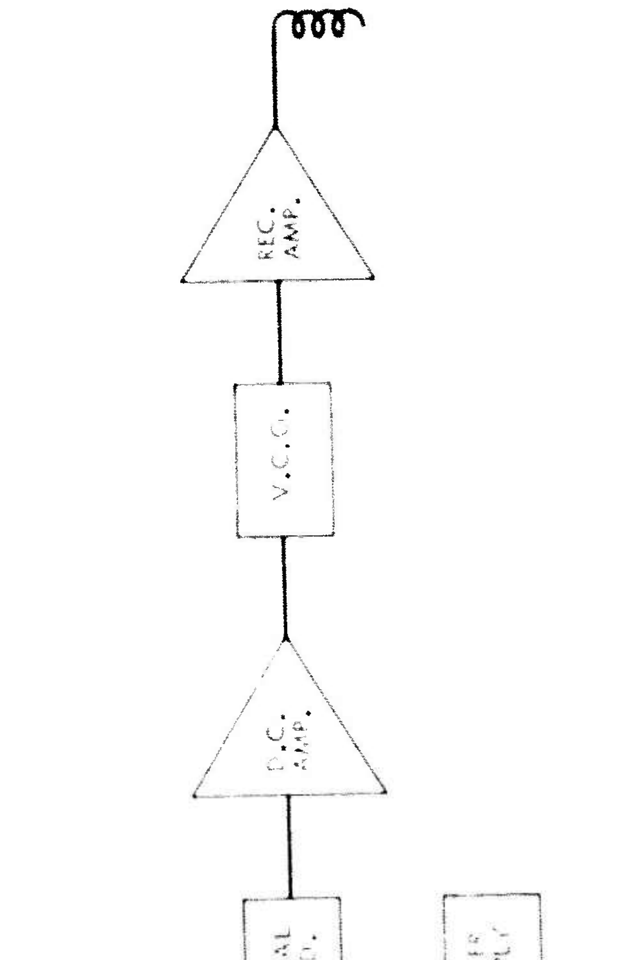


FIG. 16 THE FM RECORDING SYSTEM

likely to be a limiting component in cook-off when protection was provided on the bomb. Because of its high usage by the Fleet, cook-off protection of the Fuze M904E2 was given first priority.

The Nose Fuze M904E2 weighs about 2-1/3 pounds and it has an aluminum body; it is approximately 9-¼ inches long and it has a 2.0 inch thread which screws into the M148 Adapter Booster. When assembled into the bomb the fuze protrudes approximately 4-1/8 inches (Figure 17). The M904E2 Fuze Booster contains approximately 74 grams of tetryl. Figure 18 shows a sectional and exploded view of the fuze in the unarmed position.

The arming of the Fuze M904E2 is accomplished by rotation of an arming vane and it must turn freely in the air stream when the bomb is released.

There are three positions on the side of the fuze which must not be covered by any fixed insulator that is employed for fire protection. One is the observation window where the safe or armed position of the fuze is observed. The second is a stop screw which needs to be removed for arming times below 6 seconds. The third is the setting index locking pin which when depressed releases an internal lock so that the knurled delay setting knob may be rotated.

The M148 (T45E7) Adapter Booster (Figure 19) is used in conjunction with the M904E2 Mechenical Nose Fuze. Its overall length is 6.83 inches and the outside thread diameter is 3.5 inches. The inside diameter has a 2.0 inch thread to accommodate the Fuze M904E2. The purpose of this adapter booster is to mate the Fuze M904E2 with the Mk 80 series of bombs. It also serves to transmit the explosive train action of the fuze to the main charge of the bomb. The Adapter Booster contains approximately 180 grams of tetryl (doughnut shape) in its base and is covered with a steel closing cup.

The Mechanical Long Delay Tail Fuze Mk 346 Mod 0 is also used to a limited extent in the Mk 80 series of bombs and is of interest from a cook-off point of view. The Fuze Mk 346 is shown in Figure 20. It is approximately 6-3/8 inches long and is threaded for a two-inch adapter well. For purposes of description the term "outer" end and "base" end are used. The outer end couples to a fuze-tail drive shaft (Figure 21a). Because it is a tail fuze which is not mounted at the extreme end of the fin, the Mk 346 must be fitted with an arming assembly. The arming assembly consists of four basic components, Fuze Drive Mk 5, an adapter, drive shaft and a funnel guide. Figure 21b shows the complete arming assembly. The adapter in Figure 21b is affixed to the conical tail section by means of three socket-head set screws. The extension drive shaft couples the output spindle of the fuze drive to the input shaft of the fuze. The extension drive shaft therefore provides a direct heat path from the fire to the fuze. The funnel guide is a molded polyethylene sleeve which snaps over the outer end of the fuze. The

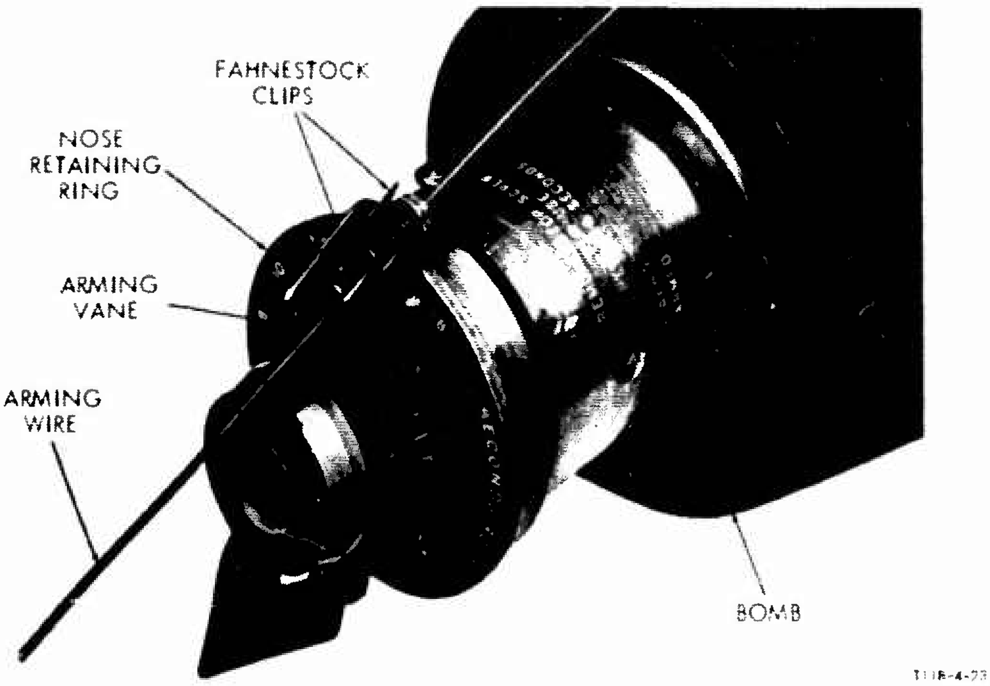


FIG. 17 M904E2 INSTALLED IN A MARK 80 SERIES BOMB

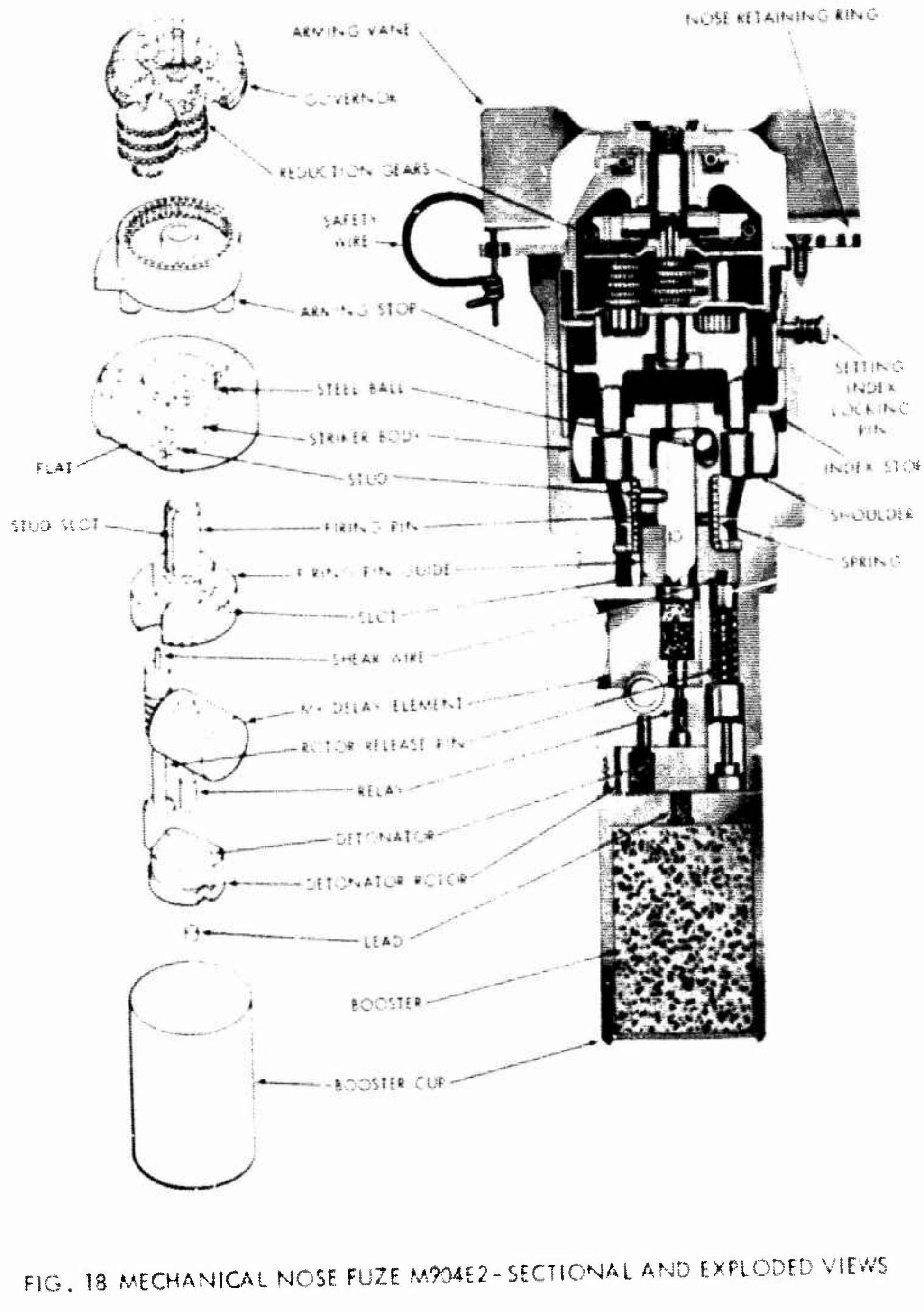


FIG. 18 MECHANICAL NOSE FUZE M904E2 - SECTIONAL AND EXPLODED VIEWS

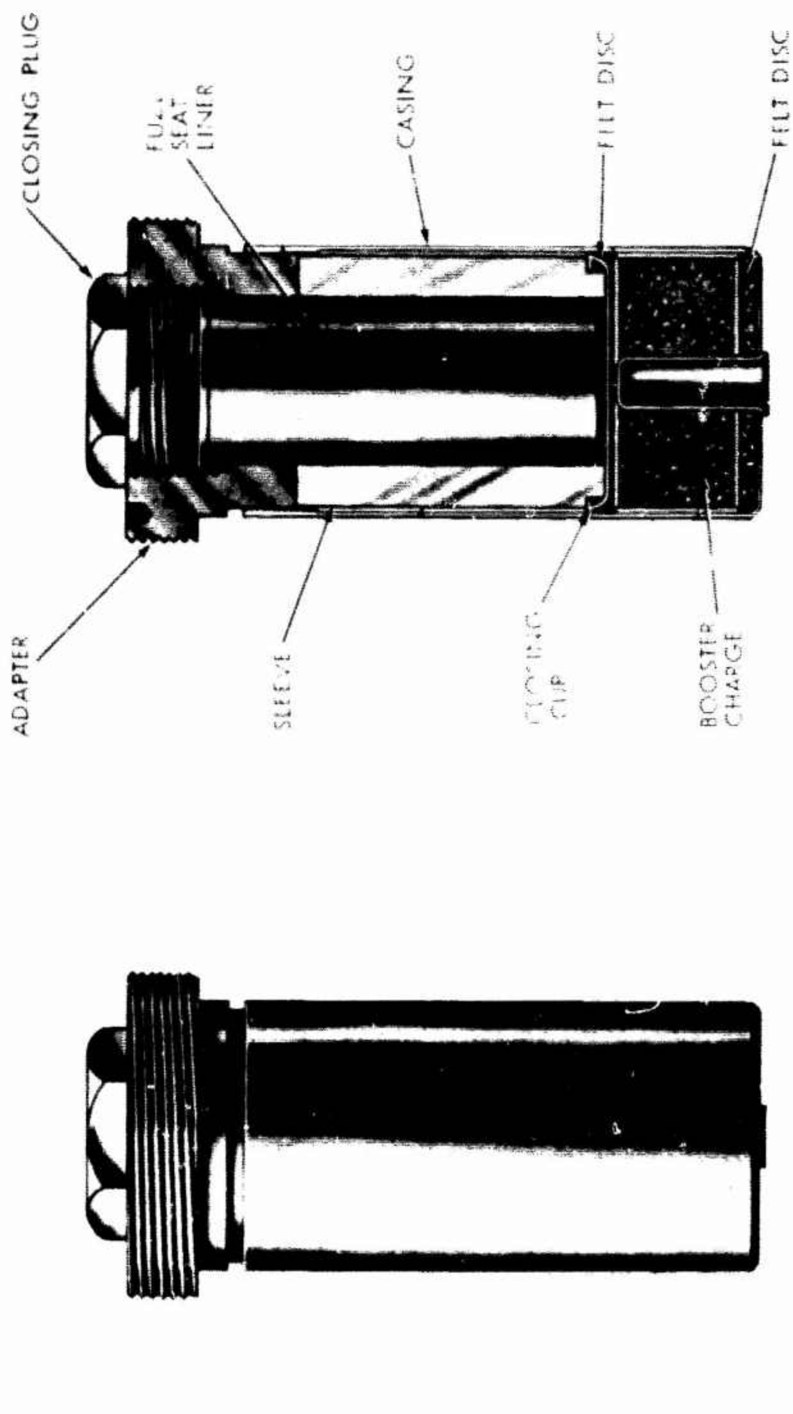
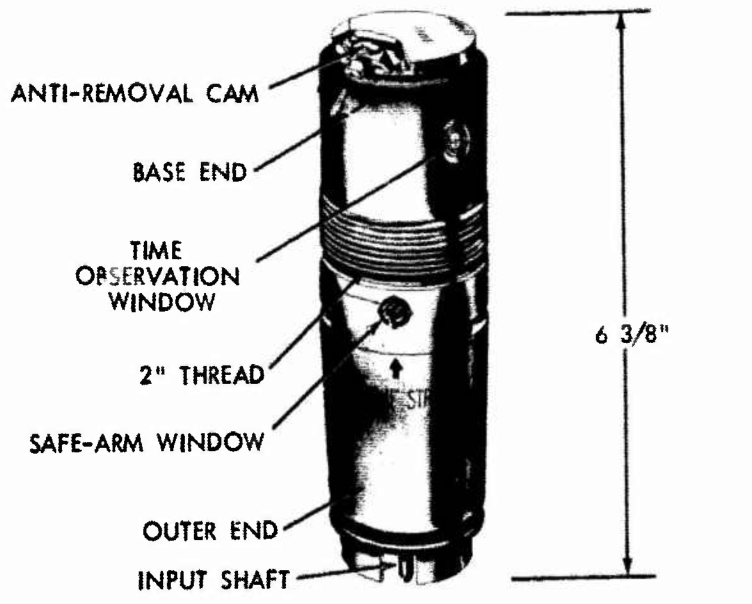


FIG. 19 ADAPTER BOOSTER T45E SERIES



TOTAL WEIGHT 4.4 LBS

FIG. 20 MECHANICAL LING DELAY FUZE MARK 346 MOD 0

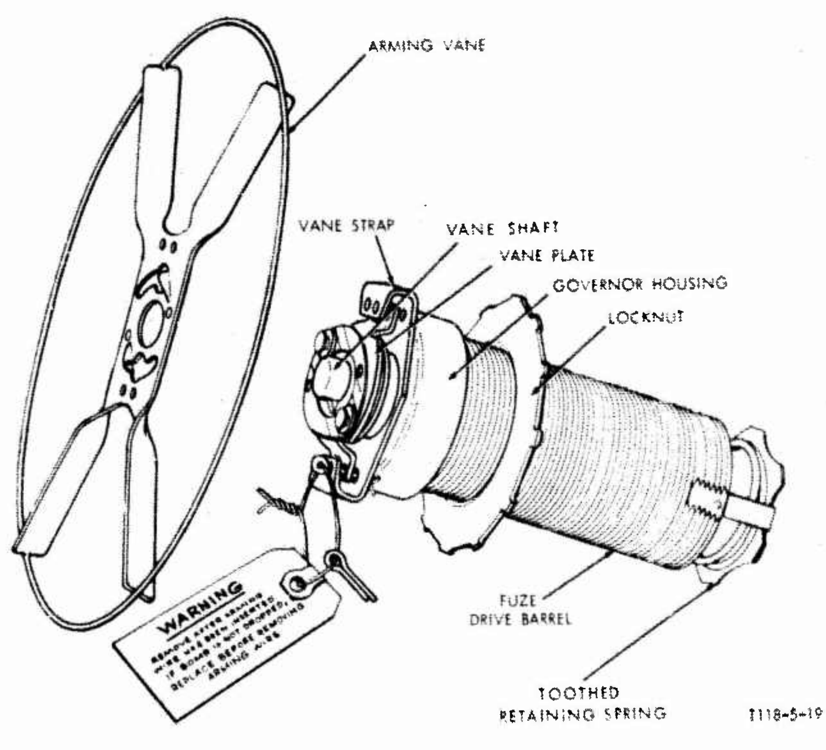


FIG. 21A FUZE DRIVE MARK 5 MOD 1

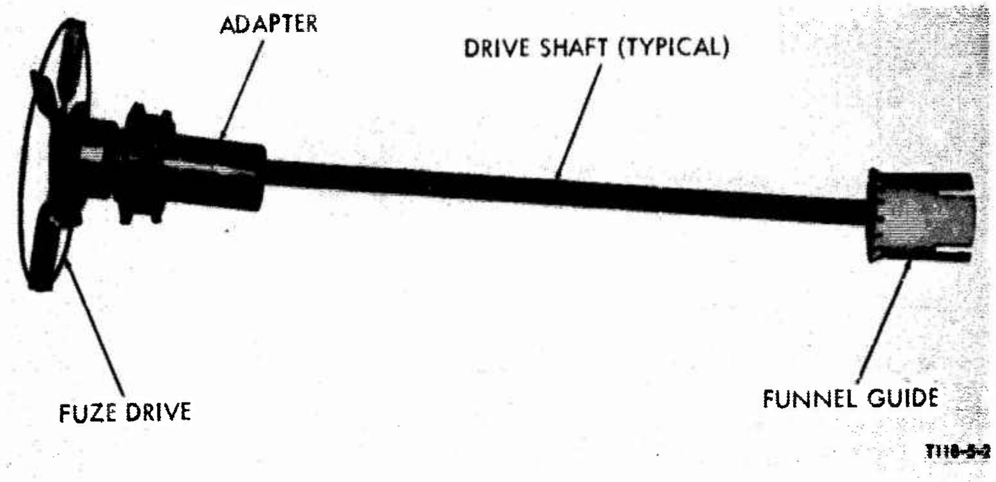


FIG. 21B TYPICAL ARMING ASSEMBLY

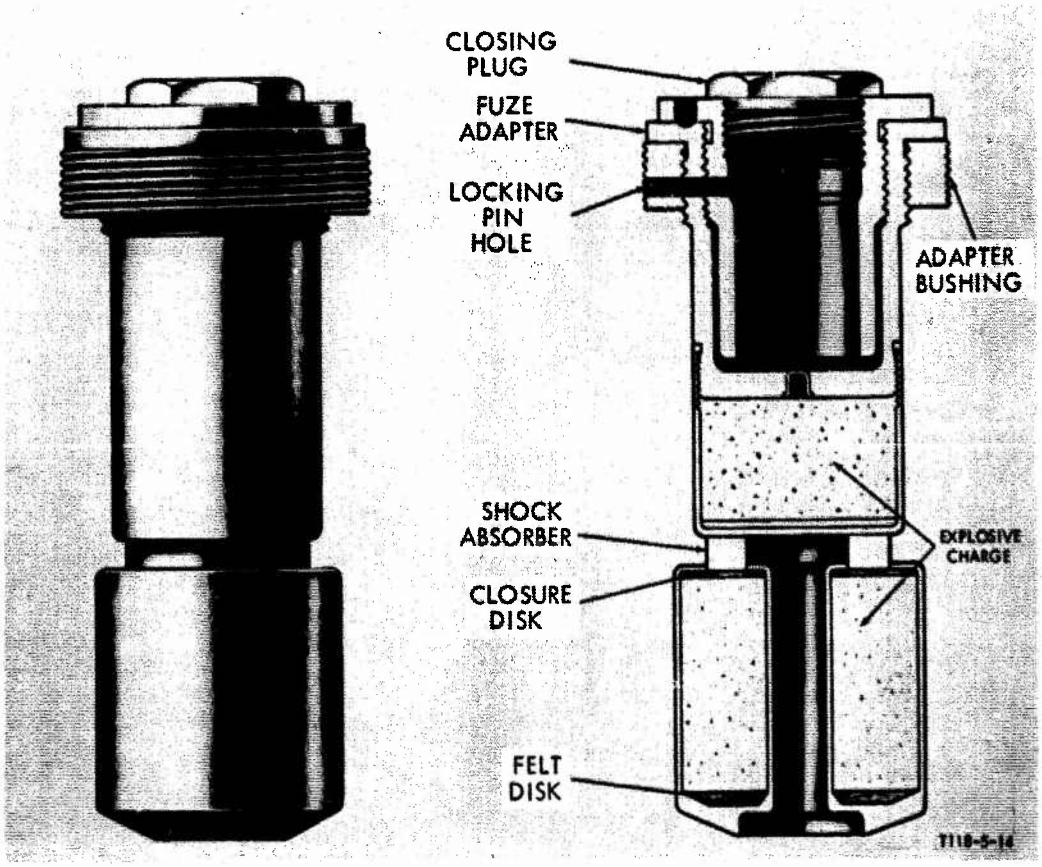


FIG. 22 ADAPTER BOOSTER T46 SERIES

base end of the fuze fits into an adapter booster well. The Adapter Booster T46 is installed into the bomb fuze well. It contains approximately 410 grams of tetryl. The overall length of the adapter booster is 8.7 inches. The outer thread diameter is 3.5 inches and the inside thread diameter is 2.0 inches to accomodate the Fuze Mk 346. The Adapter Booster T46 series is shown in Figure 22. The only explosive components integral to the fuze are a detonator and lead. It is unknown how these components react under intense heat.

GENERAL PURPOSE 500-POUND MARK 82 BOMB

The Mark 82 Bomb has a cylindrical body with an ogival nose. A conical fin is attached to the aft end of the bomb body by set screws. The length of the assembled bomb is 86.90 inches. The fin span is 15.1 inches. The average weight of the explosive charge is 192 pounds and the weight of the assembled bomb is 531.0 pounds. The Mk 82 bomb is shown in Figure 23.

The tubes for the electric fuze cable harness connect the nose and tail cavities with the charging well between the lugs on the outer surface of the bomb. The electric fuze cable harness was removed in cook-off tests in order to provide space for thermocouples and probes. Two suspension lugs, spaced 14 inches apart, and a hoisting lug at the center of gravity were threaded into lug inserts on the bomb body. The bombs were hung in the burning pit by means of chains attached to the suspension lugs.

DEFINITION OF TERMS

The detonation of an explosive in air causes a relatively large amount of energy to be released in a short time. A shock, or blast wave is formed at the surface and propagates outward. This shock wave starts with an initial high pressure-high velocity near the explosive and eventually decays to a sound wave at some distance from the charge. In order to classify the type of reaction occurring it is usually necessary to obtain the air blast parameters such as peak pressure, time of reaction and the length of the duration of the shock front. In the cook-off experiments which will be described, air blast procedures were used when possible to classify the type of reaction occurring. Often times however, inert bombs and live fuzes were used and insufficient explosive was present to measure the air blast parameters. Because of the high temperatures surrounding the pit, close in measurements could not be made. The following definitions of reactions as promulgated by NAVORD Message 132244Z March 1969 were used in interpreting the violence of the cook-off event.

Detonation: Munition performs in design mode. Maximum possible air shock formed. Essentially all of case broken into small fragments. Blast and fragment damage is at maximum. Severity of blast causes maximum ground crater or flight deck hole capable by the warhead.

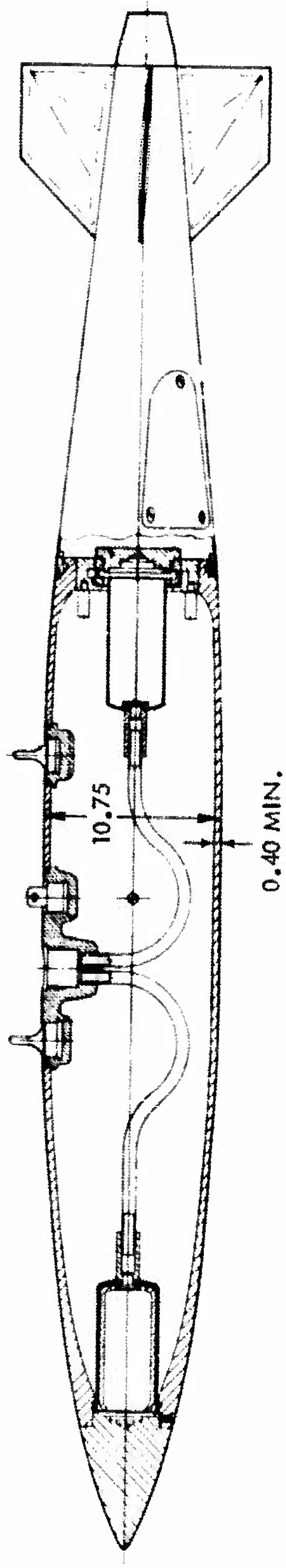


FIG. 23 MK-82 GENERAL PURPOSE BOMB

Partial Detonation: Only part of total explosive in munition detonated. Strong air shock and small as well as large case fragments produced. Small fragments are similar to those in normal munition detonation. Extensive blast and fragmentation damage to environment. Amount of damage and extent of breakup of case into small fragments increases with increasing amount of explosive that detonated. Severity of blast could cause large ground crater, or large flight deck hole on carrier if munition is large bomb; hole size depends on amount of explosive that detonates.

Explosion: Violent pressure rupture and fragmentation of munition case with resulting air shock. Most of metal case breaks into large pieces which are thrown about with unreacted or burning explosive. Some blast and fragmentation damage to environment. Fire and smoke damage. Severity of blast could cause minor ground crater, or small depression on flight deck of carrier if munition is large bomb.

Deflagration: Explosive in munition burns. Case may rupture or end plates blow out; however, no fragmentation of the case. No fragments are thrown about. Damage to environment due only to heat and smoke of fire. No discernable damage due to blast or fragmentation.

EXPERIMENTAL RESULTS AND CONCLUSIONS

The first series of tests were performed to establish a baseline for an unprotected Nose Fuze M904E2 and Adapter Booster M148 (T45E7). A Tail Fuze Mk 346, Adapter Booster T46 and an arming assembly were also included in this test to ascertain their cook-off characteristics. Ionization probes were utilized to determine the site of the reaction. It was decided if the Tail Fuze Mk 346 Adapter Booster combination reacted first, they were to be eliminated from the program and investigated at a later date following a solution to the Fuze M904E2 and M148 Adapter Booster combination. The Mk 346 Fuze and T46 Adapter Booster assembly therefore rode piggy-back to the Fuze M904E2 program.

The Mk 82 Bombs used during this series of tests were thermally protected bombs produced by NAD, Crane. The bomb casings were the regular production type and were insulated on the interior with $\frac{1}{4}$" of high melting hot melt. The exterior surface was protected with 15 mils of an intumescent paint manufactured by Cheesman Elliot and Company.

The ionization probes were 28 gauge chromel-alumel wire and were placed in the charging wells in six different locations. Eight thermocouple wires were placed symmetrically around the bomb to obtain the fire temperature. The bomb was suspended 36" above 2,500 gallons of JP-4 jet fuel in a 35' x 35' x 1' deep enclosure. The experimental set up is shown in Figure 24. The probe locations are shown in Figure 25. A wind velocity for firing of 3 knots or

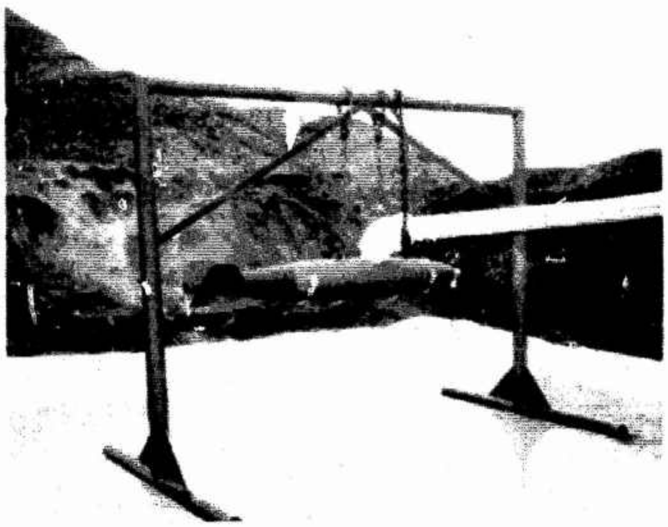


FIG. 24 PHOTOGRAPH OF THERMALLY PROTECTED LIVE MK 82 BOMB OUTFITTED WITH MK 346 TAIL FUZE AND M-904E2 NOSE FUZE

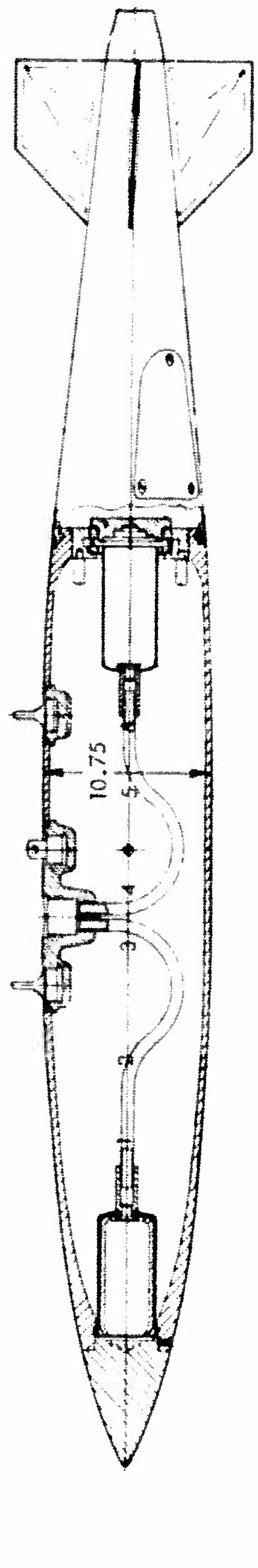


FIG. 25 IONIZATION PROBE LOCATION IN MK 82 THERMALLY PROTECTED BOMB

less was generally observed. The fuel was initiated by means of four thermite grenades positioned at each end of the pit. The thermocouple data was recorded on paper tape and the probe data on magnetic tape.

Fuze Test No. 1

The first test of the Nose and Tail Fuze combination in an H-6 loaded and protected bomb gave a reaction five minutes and eighteen seconds (318 seconds) after the start of the fire. The average fire temperature was 1750°F and it burned for 16 minutes. Pin probe data indicated that the start of the reaction occurred in region 1, nearest to the M904E2 and M148 Adapter Booster. The bomb was blown into several large pieces and a slight overpressure was detected. Figure 26 shows a representative case fragment. The reaction was classified as an explosion.

Fuze Test No. 2

In the next test the same configuration as above was exposed to the fuel fire. The atmospheric conditions were similar to the previous shot and the wind velocity was 1-2 knots. The average fire temperature was 1600°F. The ionization probes were located in the charging wells identical to Figure 25. A top view of the set-up is shown in Figure 27. Seven minutes and fifty-five seconds (475 seconds) after the start of the fire the bomb detonated. Small fragments were strewn about the area and a crater approximately eight feet in diameter and one foot deep was formed. A photograph of the area after the shot, Figure 28, shows the crater and case remnants of the detonation. Air blast over pressure measurements were also recorded. The close in gauge was driven off scale and the second gauge recorded a small overpressure. The over pressure measurement is shown in Figure 29. The steep initial pressure rise and the shape of the curve is indicative of a detonation. The average fire temperature in this run was lower than in the previous experiment which could account for the difference in cook-off times. The ionization probe data for this experiment indicated that the reaction initiated in the position where the tail fuze was located. As a result of this test the tail fuze investigations were set aside for future consideration.

Fuze Test No. 3

Another test was made with the same configuration as in Fuze Test No. 2 except the tail fuze and adapter booster were removed. The wind conditions were calm. Five minutes and forty-two seconds (342 seconds) after the start of the fire the bomb exploded. The nose of the bomb was blown 6 to 7 feet from the supporting stand. Small pieces of unburned explosive were found in the pit and at the surface. The bomb was essentially blown into 10 large fragments. Representative pieces of the bomb are shown in Figure 30. No probe data was taken in this shot. A small overpressure was observed with the close in air blast gauge. From the air blast curve

FIG. 26 REPRESENTATIVE CASE FRAGMENT
FROM TEST FUZE NO. 1

FIG. 27 TOP VIEW OF THERMALLY PROTECTED LIVE MK 82 BOMB CONTAINING MK 346 TAIL FUZE AND M-904E2 NOSE FUZE-FUZE SHOT NO. 2

FIG. 28 CRATERING AND CASE REMNANTS OF FUZE TEST NO. 2

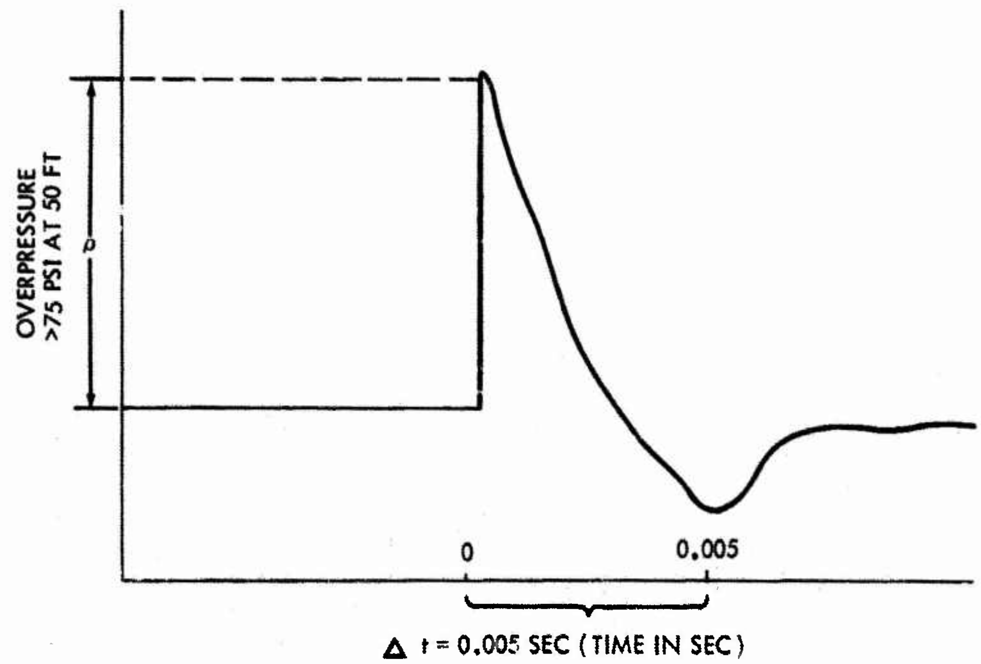


FIG. 29 ACTUAL AIR BLAST TRACE OF FUZE TEST NO 2

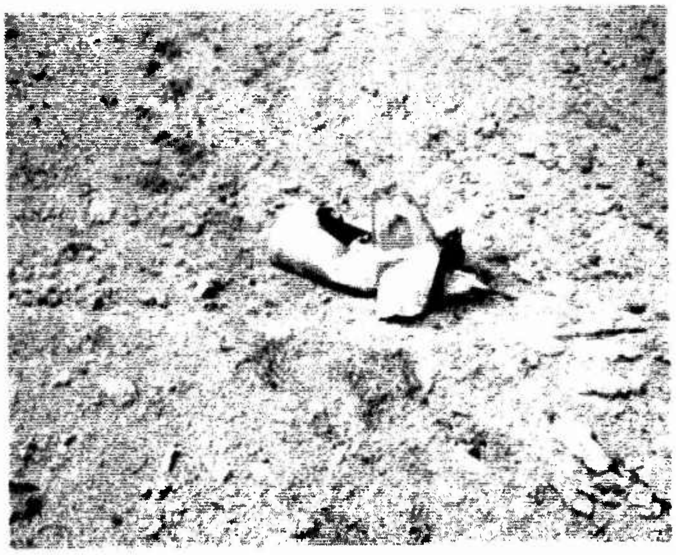


FIG. 30 BOMB FRAGMENTS FROM FUZE TEST NO. 3. TOP VIEW SHOWS TAIL SECTION. BOTTOM VIEW SHOWS AFT END OF BOMB.

it appears as though two reactions were occurring. This is shown in Figure 31. The average fire temperature was 1650°F, similar to the fire temperature observed in Fuze Test No. 2. It appears from these results that the average cook-off time of an unprotected fuze in a thermally protected bomb is on the order of five minutes. It was immediately apparent that a fix would have to be applied to the fuze in order to extend its cook-off time and make it more compatible with the thermally protected bombs which were being tested at the Naval Weapons Laboratory, Dahlgren, Va. The thermally protected bombs proposed for ultimate Fleet issue will be coated externally with an insulation coating and internally with high melting hot melt. Cook-off times range from nine minutes to 15 minutes.

The results of Fuze Test No's. 1, 2 and 3 are tabulated in Table 17.

Since fuzes, particularly nose fuzes, cook-off first when tested in thermally protected bombs, it was decided to investigate the use of a rubber sleeve over the fuze body to delay cook-off. Candidate No. 1 sleeving was chosen because of (1) the small scale burn tests, (2) superior environmental characteristics, (3) its availability and (4) because of our familiarity with the material from previous bomb testing. From previous tests it was determined that the Candidate No. 1 sleeve must be bonded to the metal substrate to achieve maximum insulation. The adhesive which was found to be most effective was a Dow Corning Silicone Adhesive #737.

Fuze Test No. 4

A Mk 82 Bomb internally coated with ¼" high melting hot melt was filled with Filler E which is an inert simulant for explosive. The Filler E loaded bomb was fitted with an inert T45E7 Adapter Booster and live Fuze M904E2 containing the Candidate No. 1 rubber cover bonded on with the Dow Corning Silicone Adhesive. The aluminum sleeve in the Adapter Booster was instrumented with four thermocouples, the Fuze M904E2 with four thermocouples and the inert adapter booster charge with four thermocouples. Eight thermocouples were positioned 90° around the major diameter of the bomb. The thermocouple arrangement is shown in Figure 32, for the adapter booster and in Figure 33 for the Fuze M904E2. No air blast measurements were made due to the small amount of explosive present and the inability to make close in measurements because of the intense heat generated by the fuel fire. The wind velocity was 0-1 knots measured in the pit at the bomb level. Eleven minutes and sixteen seconds (676 seconds) after the start of the fire the fuze appeared to detonate. The fuze was blown approximately 900 feet from the site of the reaction and the cup containing the tetryl in the Fuze M904E2 was blown completely apart. The fire temperature was approximately 1700°F and the fuze temperature approximately 425°F before detonation. The fire burned for 15 minutes. The adapter booster temperature appeared to be approximately 350°F before the reaction. The thermocouple data is shown in Figure 34.

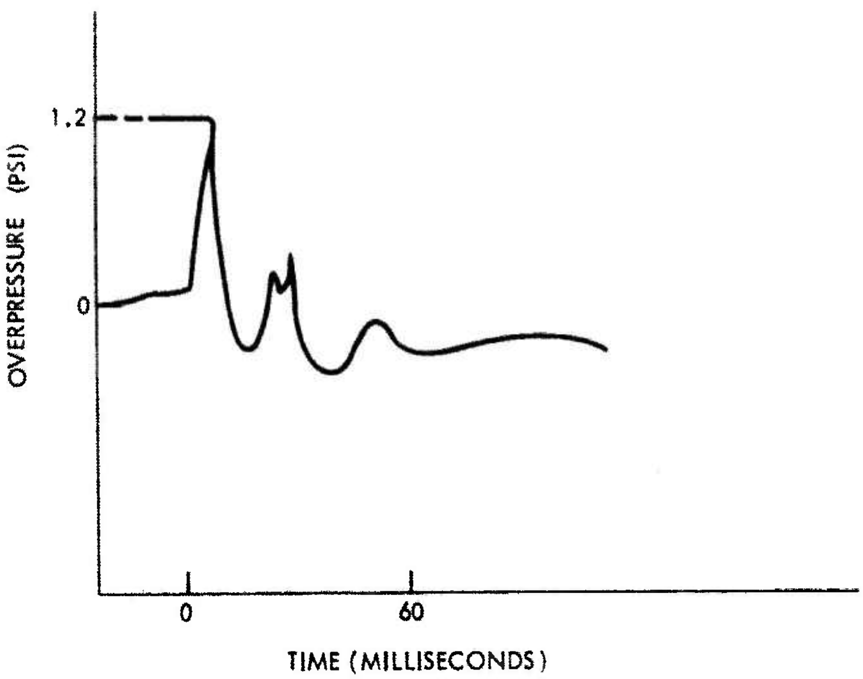


FIG. 31 AIR BLAST CURVE OF FUZE TEST NO 3

Table 17

Summary of Cook-Off Results of Thermally Protected H-6 Loaded Mk 82 Bombs with Live Fuzes

Fuze Test No.	Nose Fuze M904E2 Adapter Booster T45E7	Tail Fuze Mk 346 Adapter Booster T46E4	Reaction Time Sec.	Kind of Reaction *	Avg. Fire Temp. °F	Reaction Site
1	Live	Live	318	E	1750	M904E2 Fuze
2	Live	Live	475	D	1600	Mk 346 Fuze
3	Live	None	342	E	1650	M904E2 Fuze

* D = Detonation
E = Explosion

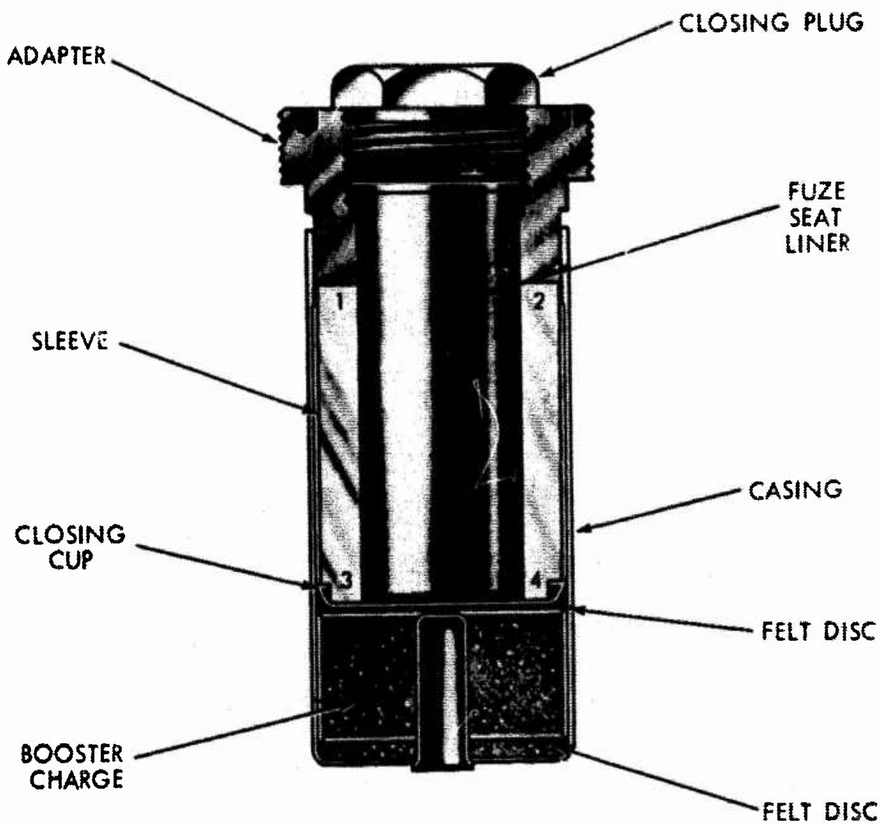


FIG. 32 THERMOCOUPLE ARRANGEMENT IN M148 (T45E7) ADAPTER BOOSTER

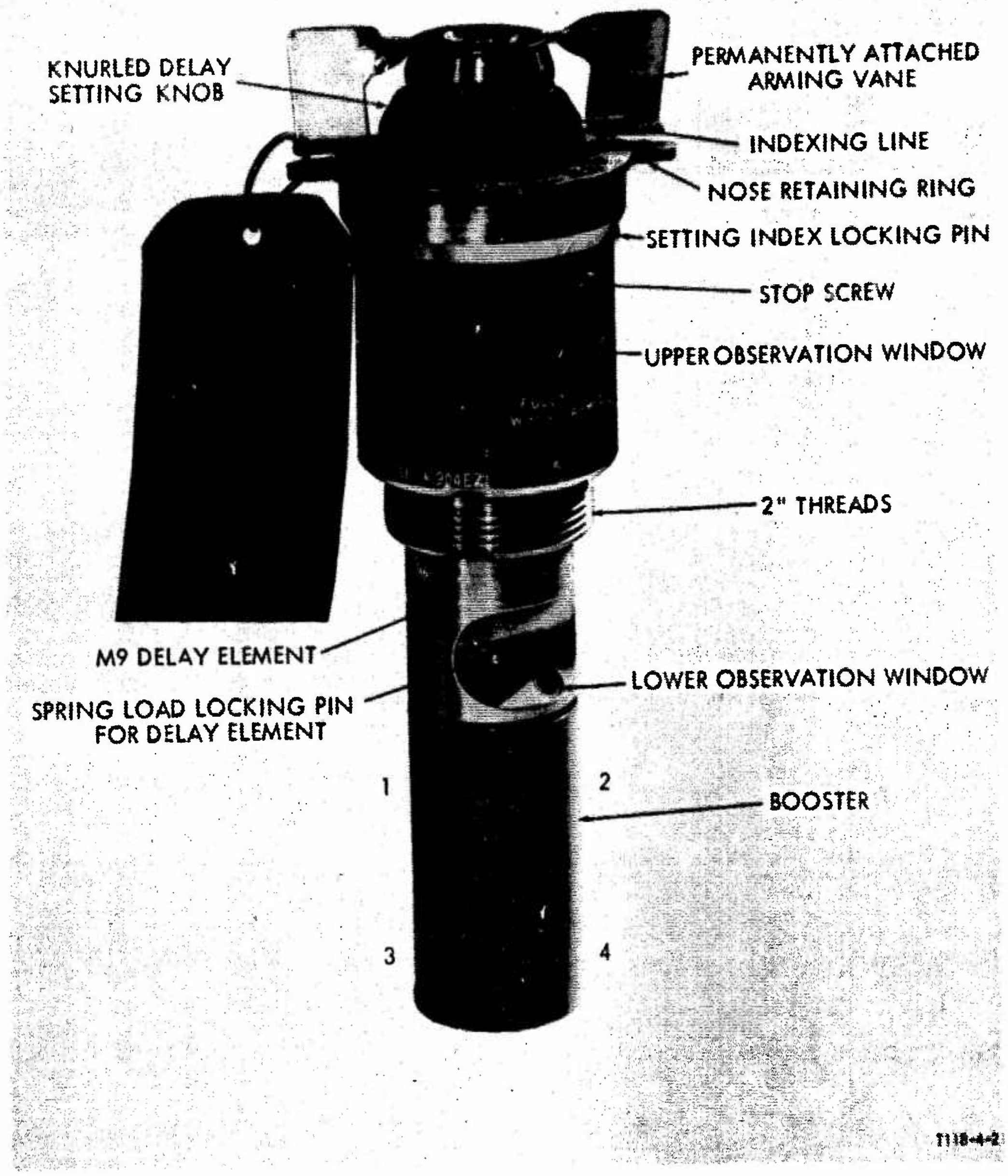


FIG. 33 THERMOCOUPLE ARRANGEMENT IN NOSE FUZE M904E2

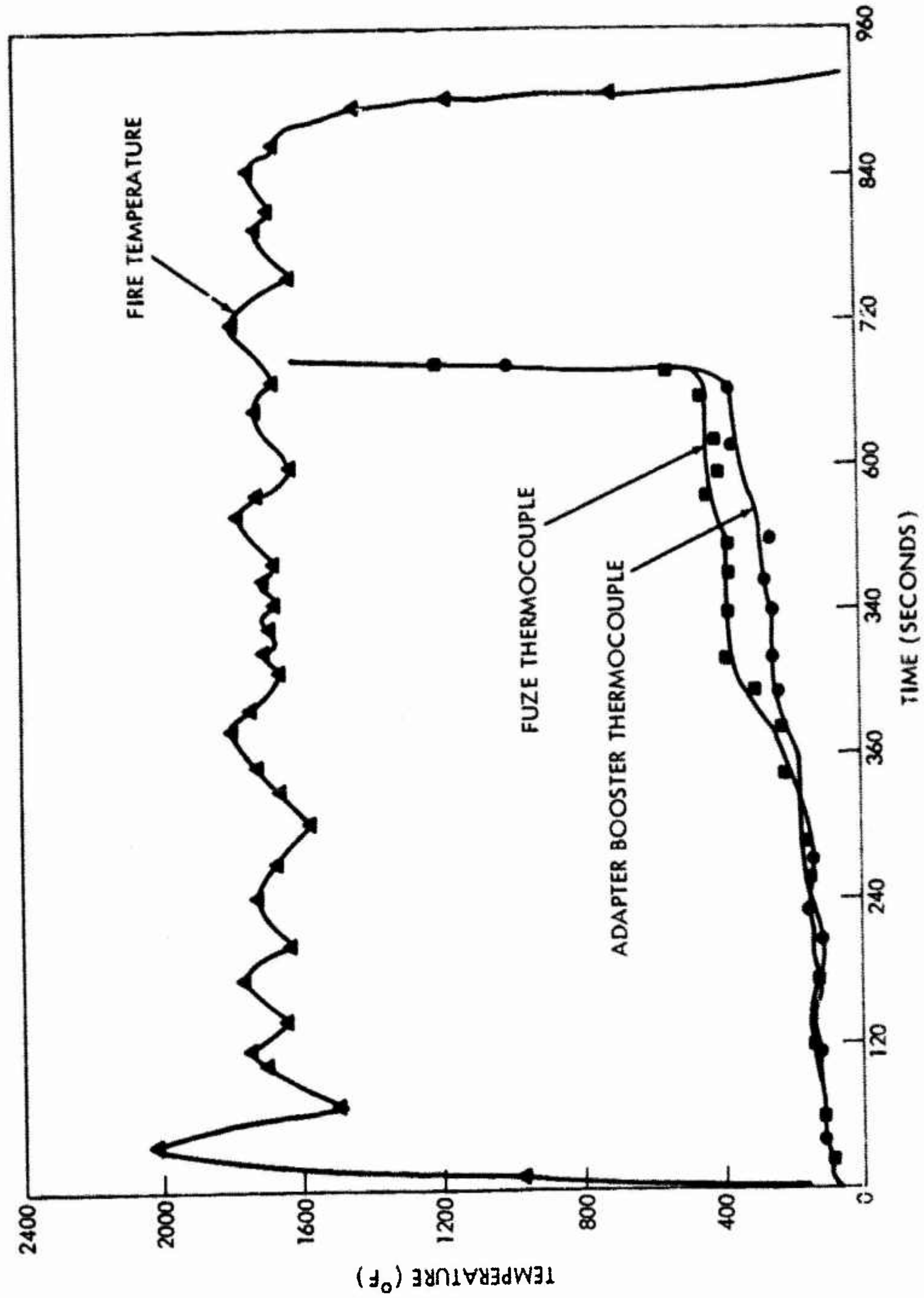


FIG. 34 TIME TEMPERATURE PLOT OF FUZE TEST NO 4

Fuze Test No. 5

Another test was run in the same manner as in the previous shot. The fuze-bomb configuration was identical to Fuze Test No. 4. The wind velocity at the bomb level was 0-1 knot. Ten minutes and thirty-eight seconds (638 seconds) after the start of the fire the fuze detonated. The cup containing the tetryl was blown apart and the aluminum sleeve was also destroyed. The average fire temperature was 1700°F. The fire burned for 15 minutes and twenty seconds. The thermocouple registering the highest temperatures for the fuze, adapter booster and fire temperature are shown in Figure 35. The maximum difference between the four thermocouples was 50°F.

Fuze Test No. 6

In order to ascertain the vulnerability of the Adapter Booster M148 (T45E7) a live Nose Fuze M904E2 was protected with Candidate No. 1 sleeve in an identical fashion to the two previous experiments. However, this time a live T45E7 unfixed Adapter Booster was used. An inert bomb with ½" high melting hot melt liner, Filler E, and intumescent paint was again used as the test vehicle. Four thermocouples were again used in the adapter booster to detect the time and temperature of the reaction. Eight thermocouples were used to measure the outside fire temperature. The wind velocity was 0-1 knot. Engulfment was complete. Six minutes and forty-seven seconds (407 seconds) after the start of the fire the adapter booster deflagrated expelling the Nose Fuze M904E2. The fuze was recovered intact. The aluminum sleeve was still intact in the bomb, although welded to the walls because of the intense heat of the burning explosive. Thermocouple data indicated that the average fire temperature was 1650°F. The cook-off temperature of the adapter booster explosive was 375°F. The thermocouple record is shown in Figure 36. It was observed in this fuze test that Filler E appeared to contribute to the burning of the adapter booster, therefore, it was decided to discontinue using this simulant in future cook-off tests.

Fuze Test No. 7

Thus far fixed M904E2 Fuzes and unfixed live and inert M148 (T45E7) Adapter Boosters has been tested in inert bombs. The configuration for this test consisted of a live Fuze M904E2 outfitted with a Candidate No. 1 sleeve bonded onto the fuze body with Silicone Adhesive #737. The live fixed nose fuze was inserted into an unfixed Adapter Booster T45E7 and this in turn was installed into a live thermally fixed bomb containing H-6 explosive. The wind velocity in the pit was 0-3 knots, however, there were occasional gusts up to 5 knots. The average fire temperature was 1600°F shown in Figure 37. No thermocouples were installed into the fuze or bomb for this test. Eight minutes and fifty seconds (530 seconds) after the start of the fire the adapter booster reacted

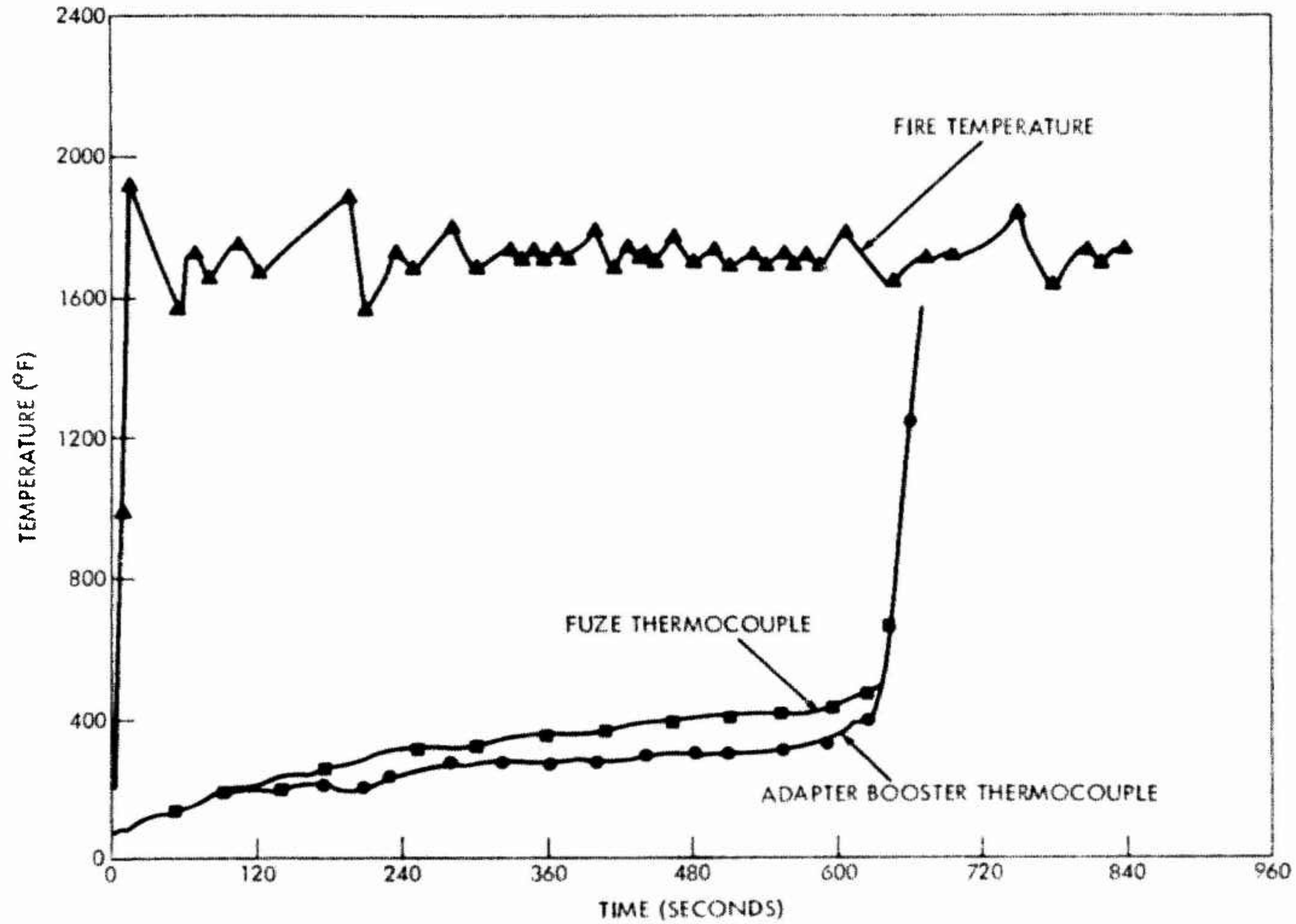


FIG. 35 TIME TEMPERATURE PLOT OF FUZE TEST NO 5

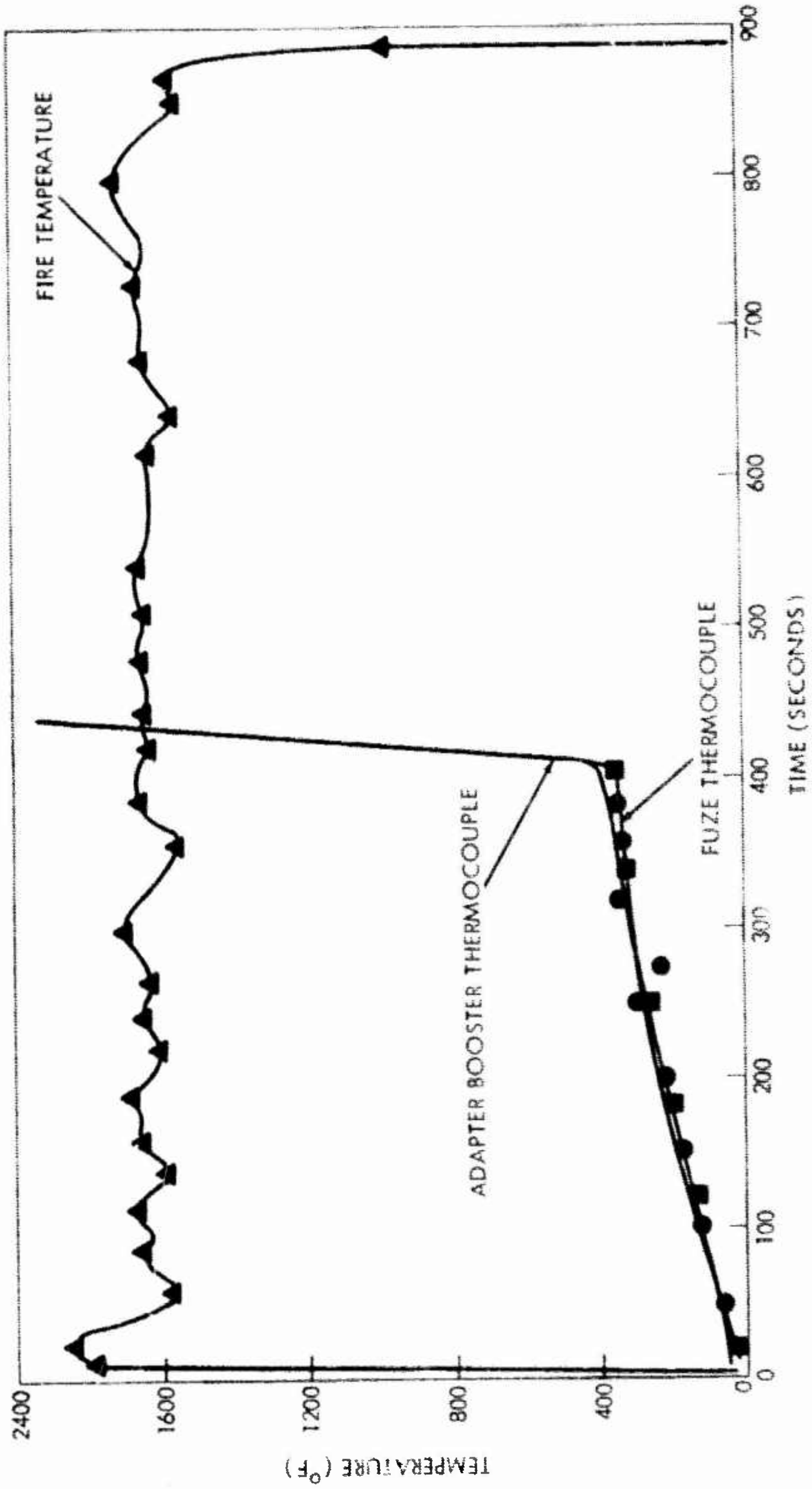


FIG. 36 TIME TEMPERATURE PLOT OF FUZE TEST NO 6

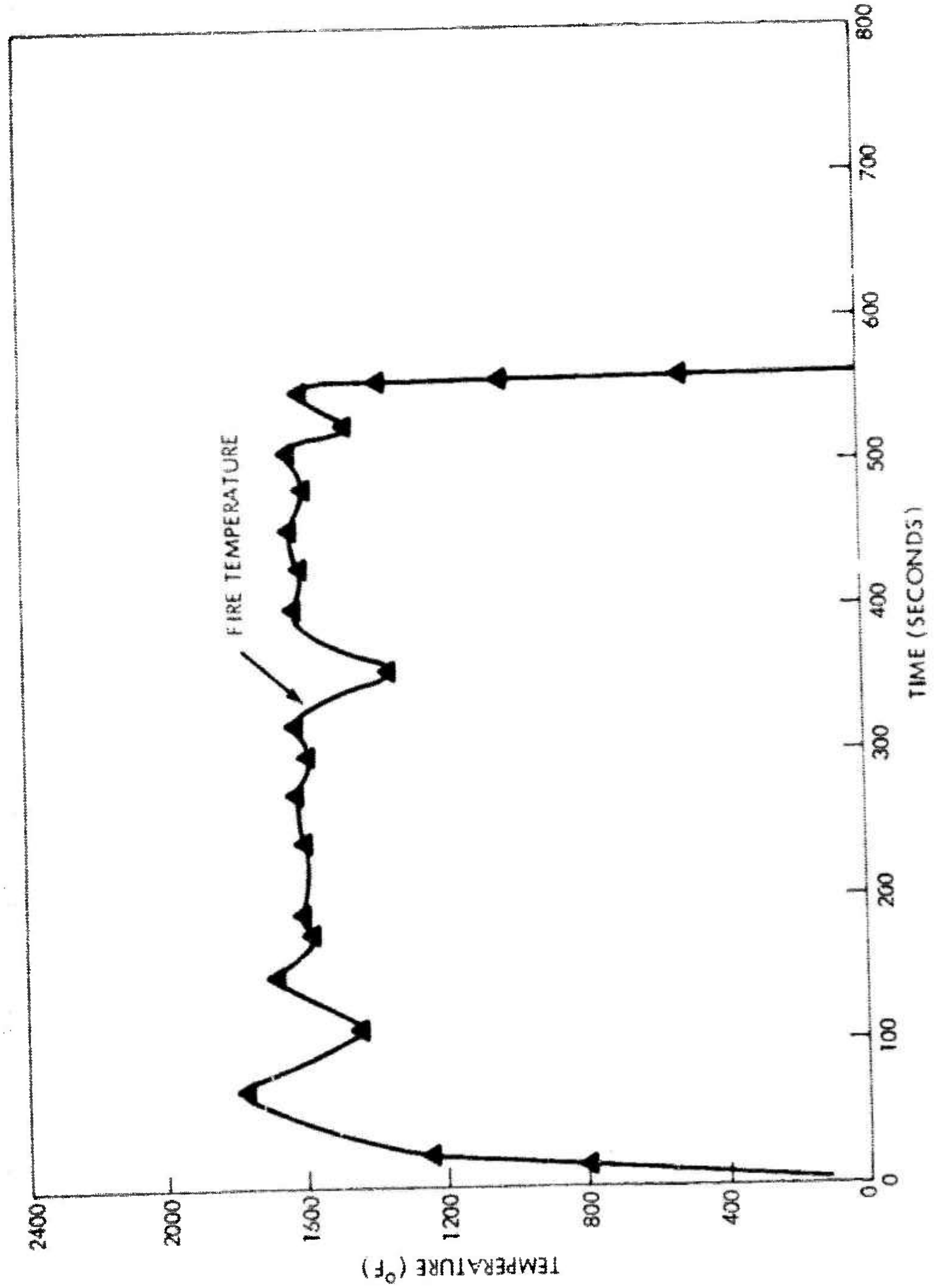


FIG. 37 TIME TEMPERATURE PLOT OF FUZE TEST NO 7

expelling the fuze, and leaving most of the fuze intact. Nine minutes and twenty seconds (560 seconds) after the start of the experiment the fire died out. At 11 minutes and 20 seconds or two minutes later the mass of the explosive in the bomb exploded splitting the case into several large fragments. This was observed on closed circuit television. It indicates that once a bomb has been heated in a fuel fire it is still subject to reaction even after the bomb is no longer engulfed in flame.

Fuze Test No. 8

The same configuration was used as in Fuze Test No. 7. Eight outside thermocouples were used to record fire temperature. Four thermocouples were positioned in the bottom of the adapter booster well to record the booster action. The adapter booster thermocouple location is shown in Figure 38. Cook-off resulted 6 minutes and 24 seconds (384 seconds) after ignition of the fuel. The action resulted in adapter booster ignition and fuze ejection. The Fuze M904E2 was recovered intact approximately 100 yards from the pit. Ten minutes and sixteen seconds (616 seconds) after ignition the bomb deflagrated. The average fire temperature was 1650°F. This is shown in Figure 39. A photograph of the test set up is shown in Figure 40.

Fuze Test No. 9

Fuze Test No. 9 was run in order to establish a baseline time for adapter booster cook-off. An inert Fuze M904E2 equipped with the Candidate No. 1 sleeve material bonded with Silastic 737 was inserted into a live T45E7 Adapter Booster. An inert sand filled thermally protected bomb was used as the test vehicle. The thermocouple arrangement was identical to those in the previous experiment. The average fire temperature in this experiment was 1575°F. A typical thermogram is shown in Figure 41. Seven minutes 28 seconds (448 seconds) after ignition of the fuel the adapter booster reacted. The resultant action was a partial detonation, destroying the adapter ring of the Adapter Booster and part of the fuze. This time, however, the front of the bomb was not peeled back as in other violent actions.

These results clearly establish that a material such as Candidate No. 1 sleeve when bonded properly onto a Fuze M904E2 will extend the cook-off time of the fuze. It also shows, however, that when this is accomplished the adapter booster becomes the weak link and must be thermally protected. The results of the tests using Candidate No. 1 sleeve is summarized in Table 18.

Fuze Test No. 10

It was decided to explore the worth of a Neoprene sleeve in accordance with Federal Specification 22T-831, Amendment 2 on the Fuze M904E2. Neoprene tubing $\frac{1}{4}$" wall thickness was bonded to a live

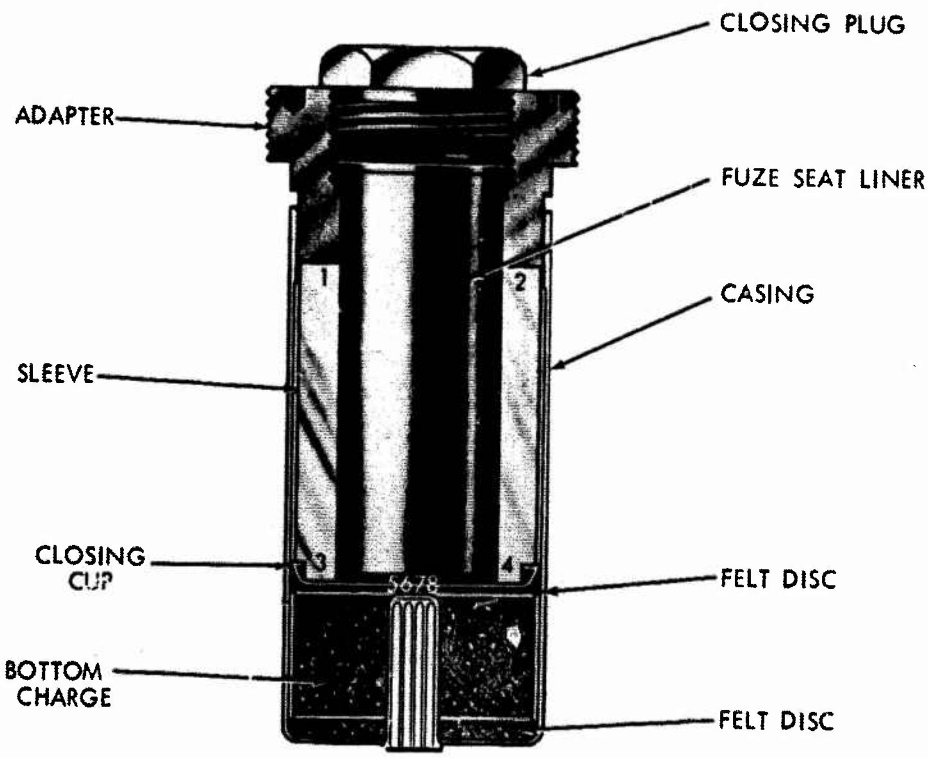


FIG. 38 THERMOCOUPLE LOCATION IN ADAPTER BOOSTER WELL - FUZE TEST NO. 8

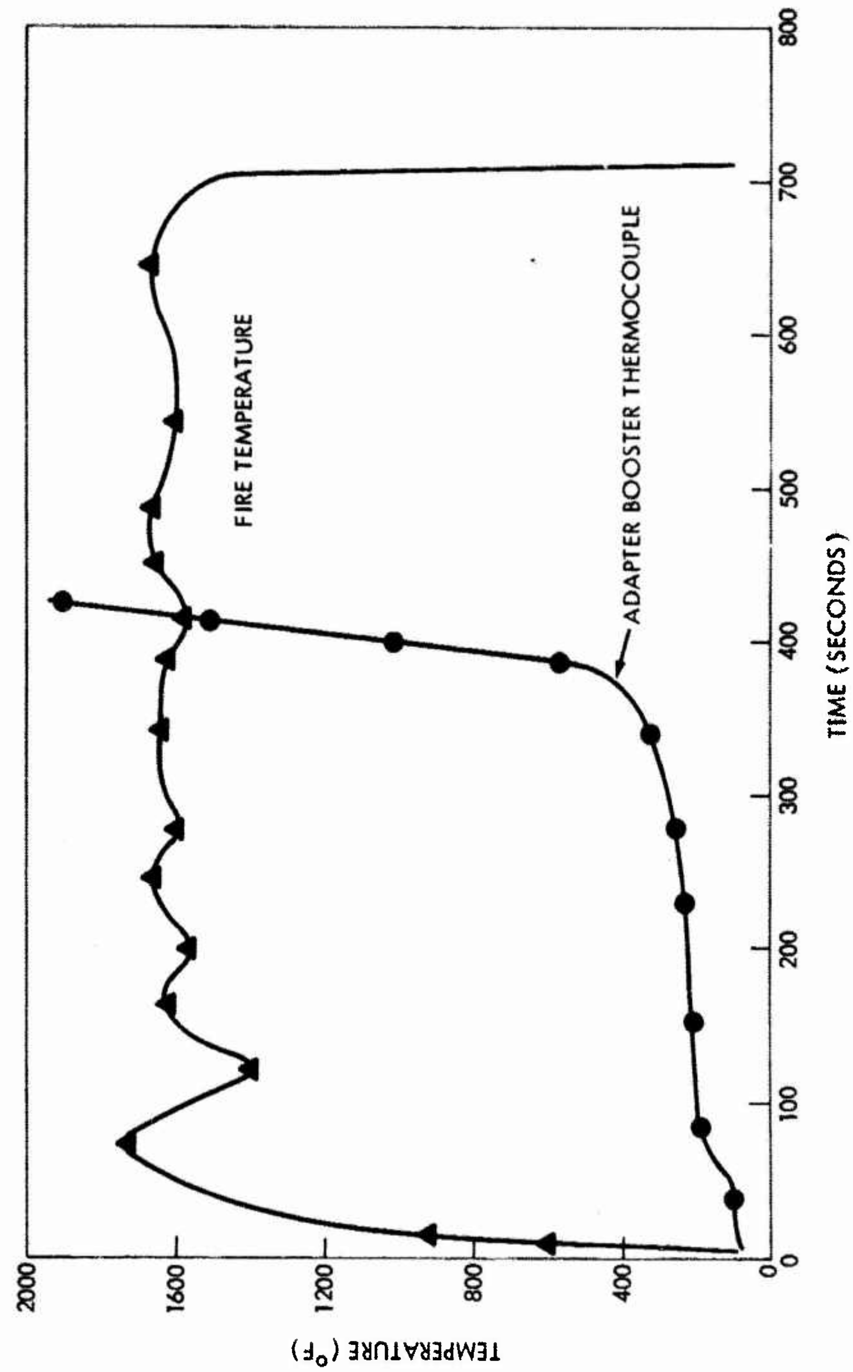


FIG. 39 TIME TEMPERATURE PLOT OF FUZE TEST NO 8

FIG. 40 TEST SET UP FOR FUZE TEST NO. 8

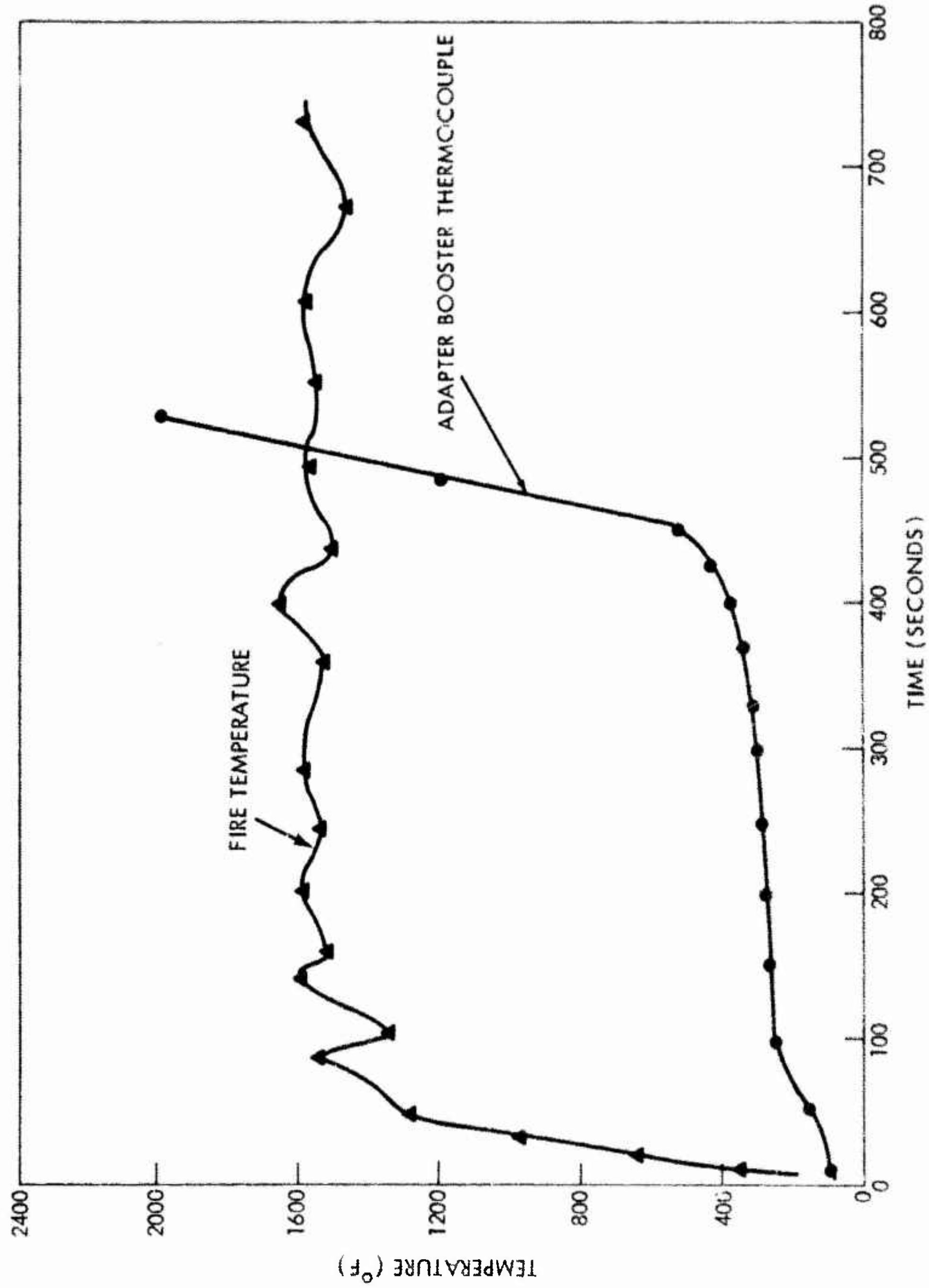


FIG. 41 TIME TEMPERATURE PLOT OF FUZE TEST NO 9

Table 18

Cook-Off Results on Fuze M904E2 Equipped with Candidate No. 1 Sleeve and Mounted in Thermally Protected Mk 82 Bombs

Fuze Test No.	Nose Fuze M904E2 Configuration	T45E7 Inert Booster	Bomb Mk 82 Configuration	Reaction Time Sec.	Type of Reaction
4	Live - Fixed with Candidate No. 1 Sleeve*	Inert T45E7	Inert Filler E Thermally Protected	676	Fuze Detonation
5	Same as above	Same as above	Same as above	638	Same as above
6	Same as above	Live T45E7	Same as above	407	Adapter Booster Deflagration
7	Same as above	Same as above	Live Mk 82 Bomb thermally protected with H-6 explosive	530	Adapter Booster Deflagration
8	Same as above	Same as above	Same as above	384	Adapter Booster Deflagration
9	Inert - Fixed with Candidate No. 1 Sleeve	Live T45E7	Inert Mk 82 Bomb Thermally protected with Intumescent Paint	448	Adapter Booster Detonation

*Bonded to Fuze with Dow Corning 737 Adhesive.

Fuze M904E2 by means of Silastic 737. This thermally protected fuze was installed in an inert T45E7 Adapter Booster and the entire assembly installed in a Mk 82 inert sand filled thermally protected bomb. The bomb was instrumented with thermocouples, as in our previous tests. Seven minutes twelve seconds (432 seconds) after ignition of the fuel the fuze reacted. The reaction was violent and can be classified as an explosion. The plots of temperature vs time for Fuze Test No. 10 is shown in Figure 42. This thermogram, as in other cases, represents the thermocouple which recorded the highest temperatures. The cook-off temperature of the fuze appears to be 470°F. The results of this test indicate that when intumescence capability is incorporated into a rubbery neoprene type material (such as Candidate No. 1) superior thermal insulating properties result. The military specification Neoprene material was therefore eliminated from future testing based on these results and laboratory screening.

OPEN ADAPTER BOOSTER INVESTIGATIONS

As a result of the previous tests with live and inert Adapter Boosters, concern was expressed regarding the performance of the unprotected adapter booster when containing a thermally protected fuze. Even more concern was expressed when it was observed that operationally, unfuzed bombs, containing adapter boosters are brought to the flight deck without any cover on the adapter booster. Shortly before aircraft take off, the fuzes are installed into the bomb. It therefore became of interest to try and simulate a condition aboard ship where wind was blowing toward the nose of the bomb so the flames would lick into the open adapter booster cavity. Statistically, the probability of the wind blowing in the proper direction is high, since the aircraft are lined symmetrically around the fan tail. See Figure 43.

Fuze Tests No's. 11, 12, 13 and 14 were concerned with determining the vulnerability of the open adapter booster to flame impingment. These tests were run in a pit 28' x 28' x 1' deep.

Fuze Test No. 11

Two thermally protected, inert sand filled bombs were hung on one stand in the center of the pit. One bomb contained a live M148 Adapter Booster having the aluminum sleeve removed to ascertain if the removal of this highly conductive mass would influence the cook-off time. The second bomb contained a standard M148 Adapter Booster. The test was run in calm weather in order to ascertain the vulnerability of the adapter booster under calm wind conditions. The wind velocity was 0-3 knots in the pit and the atmospheric conditions were good. A photograph of the test set up is shown in Figure 44. Eleven minutes 43 seconds (703 seconds) after the start of the fire the adapter booster containing the aluminum sleeve deflagrated. Eighty-nine seconds later the adapter booster without the sleeve deflagrated. The reaction was extremely mild. See

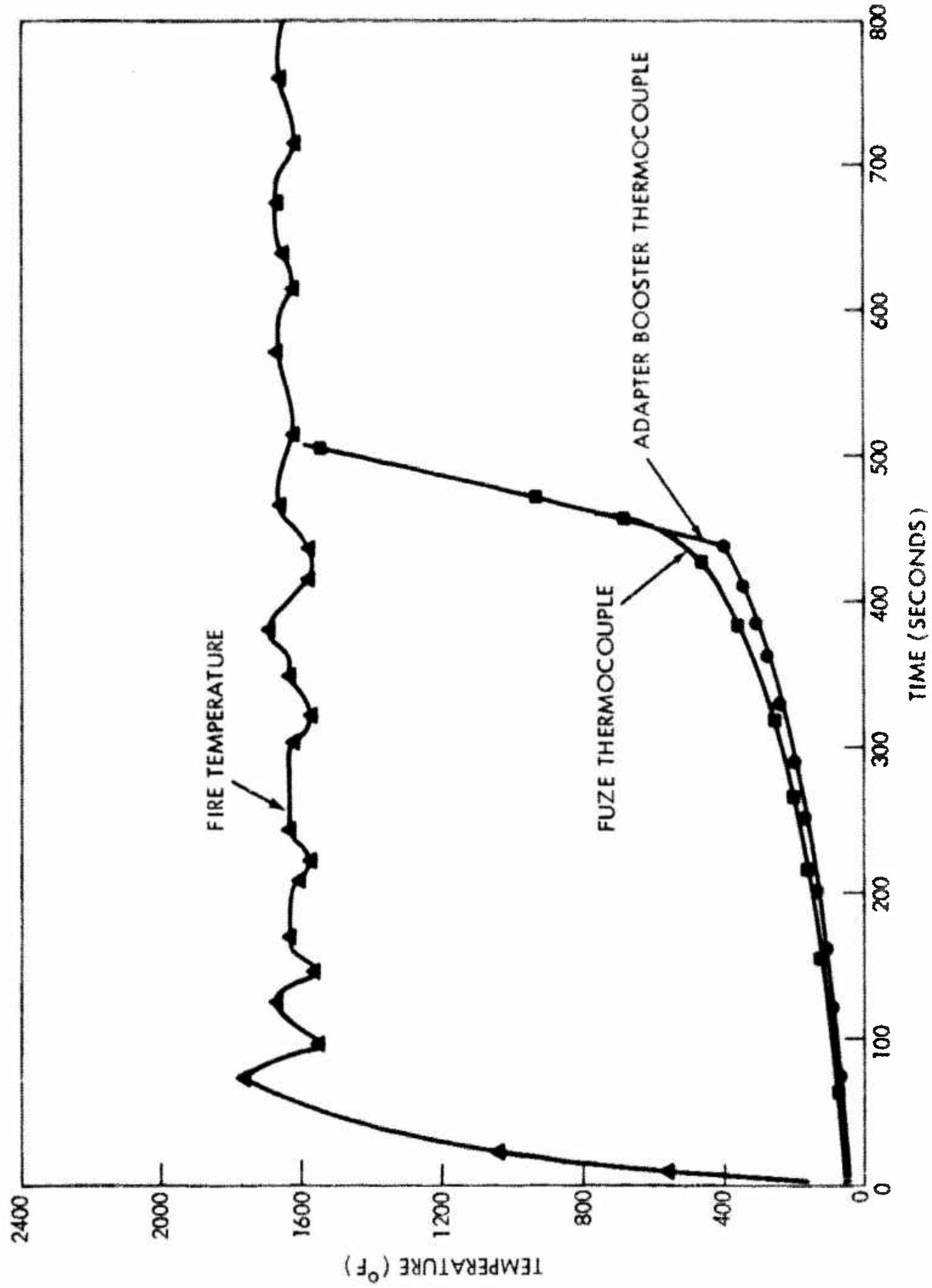


FIG. 42 TIME TEMPERATURE PLOT OF FUZE TEST NO. 10

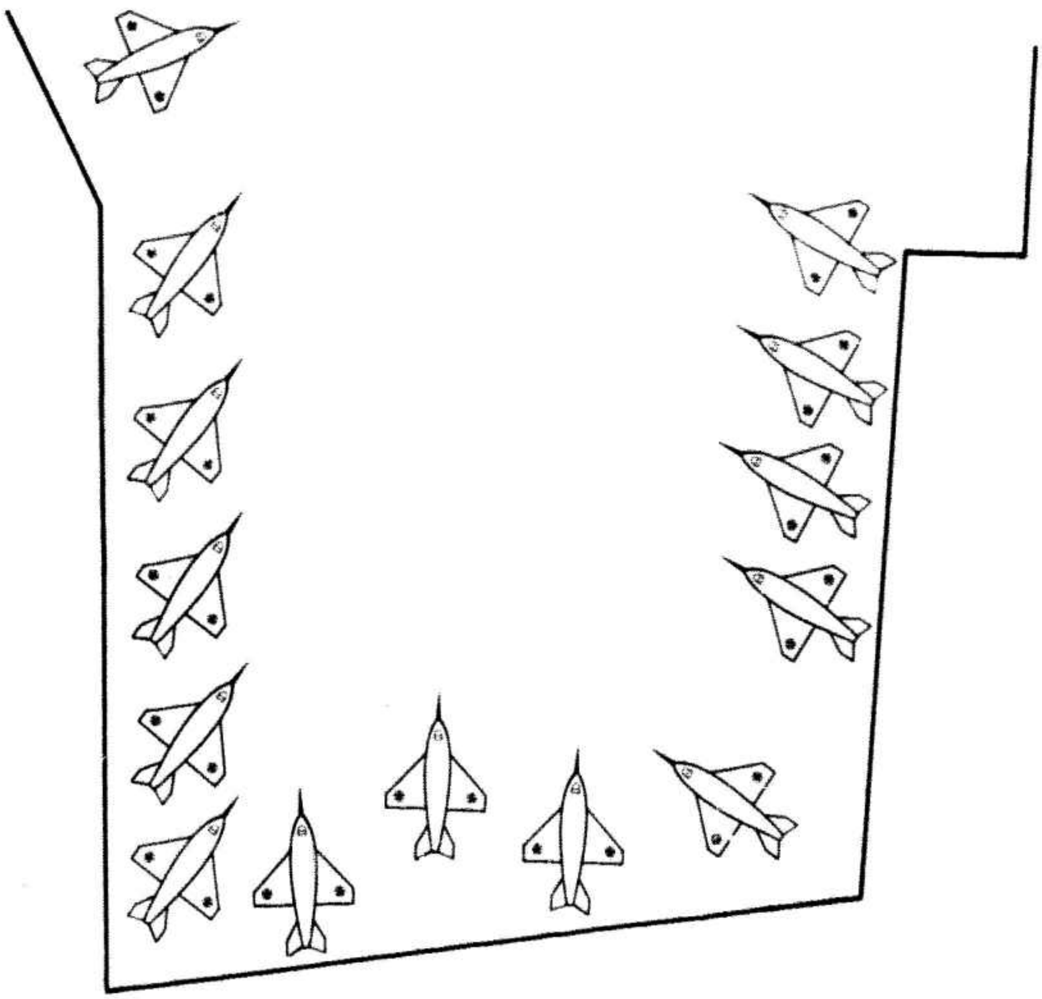


FIG. 43 TYPICAL ARRANGEMENT OF AIRCRAFT ON FLIGHT DECK

FIG. 44 PHOTOGRAPH OF TEST SET UP OF FUZE TEST NO. 11

Figure 45. From a review of 16mm motion pictures and the video tape replay it was evident that the flames did not impinge on the metal closing cup in the adapter booster cavity but they did flow over and around the open adapter booster. The fire temperature was 1600°F. The cook-off temperatures of both adapter boosters are plotted in Figure 46 together with the fire temperature. The long cook-off times of the unprotected open adapter booster suggest that the Fuze M904E2 is a strong contributor to the adapter booster problem by providing a heat path to the closing disc in the adapter booster cavity.

Fuze Test No. 12

Fuze Test No. 12 was designed to determine the vulnerability of the Adapter Booster M148 when flames were directed into the open cavity. The configuration was the same as in Fuze Test No. 11 (i.e., one Adapter Booster with sleeve and one without) except that the bombs were positioned in the direction in which the wind was blowing. The bombs were hung from a trapeze sort of arrangement which was designed so that the bombs could be moved in any direction based on the prevailing wind conditions, see Figure 47. Four thermocouples were placed symmetrically around each bomb to measure fire temperature. The bombs were suspended two feet above the fuel instead of three feet in order to ensure complete engulfment. The wind velocity was ten knots. After the fuel was ignited it was observed from the video tape replay that the fire was being directed into the booster cavity. Three minutes 46 seconds (226 seconds) later the adapter booster with the aluminum sleeve exploded. Fourteen seconds later the other adapter booster exploded. Both adapter boosters reacted quite violently destroying the aluminum sleeve and fragments were hurled toward the instrumentation bunker, see Figure 48. The time temperature plot for the adapter boosters and fire temperature are shown on Figure 49. Note the larger variation in fire temperature when the wind is blowing. The average deviation is much larger in these wind experiments.

Fuze Test No. 13

Fuze Test No. 13 was designed to repeat Fuze Shot No. 11. Two thermally protected inert sand filled bombs containing live adapter boosters with and without the aluminum sleeving were positioned 26 inches above the level of the jet fuel. The wind was four knots. Four and one-half inches of fuel was placed in the pit. The thermite grenades were ignited and buildup was quite rapid. The average fire temperature was 1550°F. Time temperature plots and fire temperature are shown on Figure 50. Thirteen minutes 30 seconds (810 seconds) after ignition of the fuel the adapter booster without sleeve deflagrated vigorously. The reaction occurred just as the fire died out. Four minutes later the adapter booster containing the aluminum sleeve exploded splitting the bomb case open. Again we see that once an explosive item is heated in a fire and is no longer engulfed the danger of a violent reaction is still great.

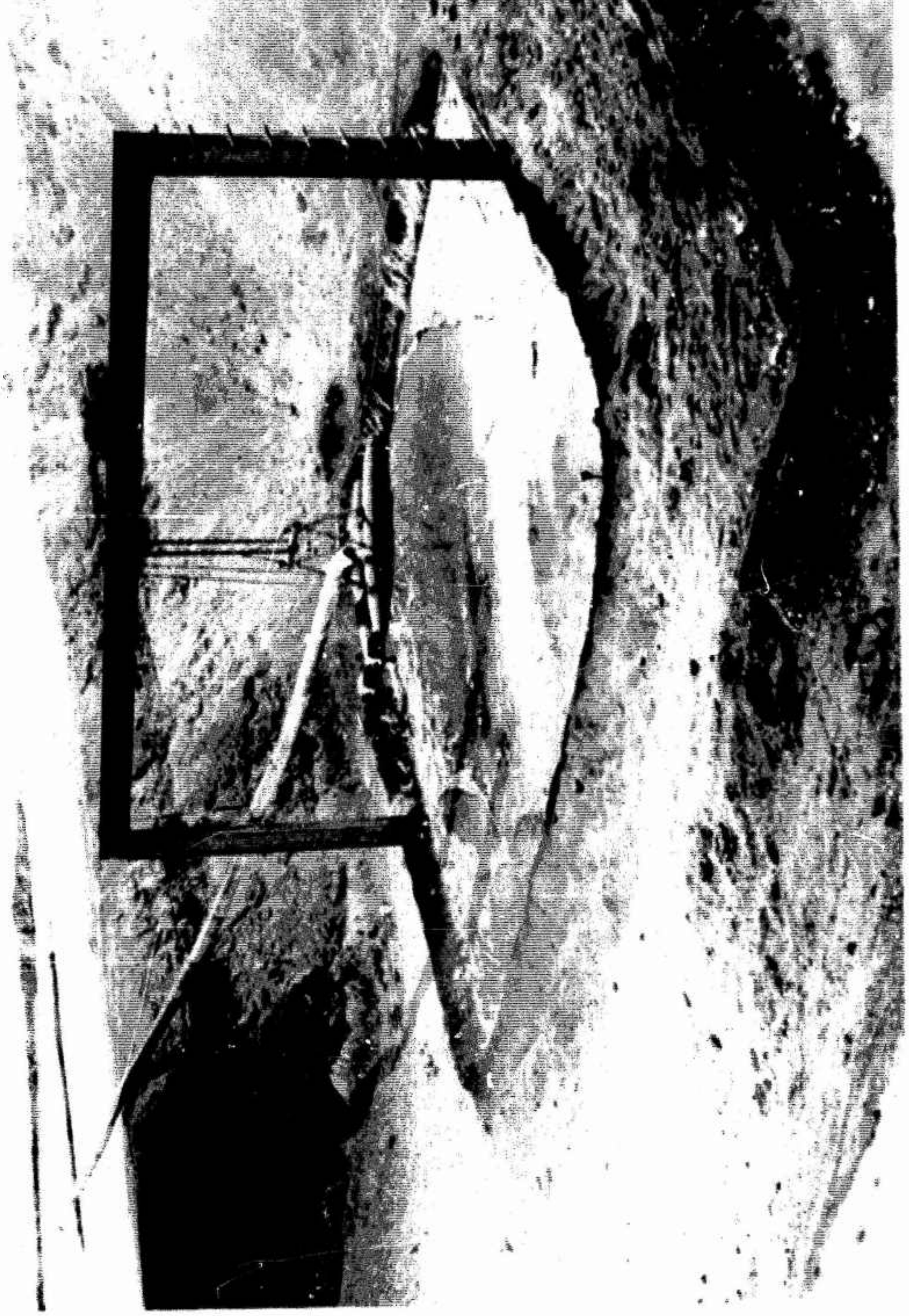


FIG. 45 PHOTOGRAPH OF TEST SITE AFTER FUZE TEST NO. 11

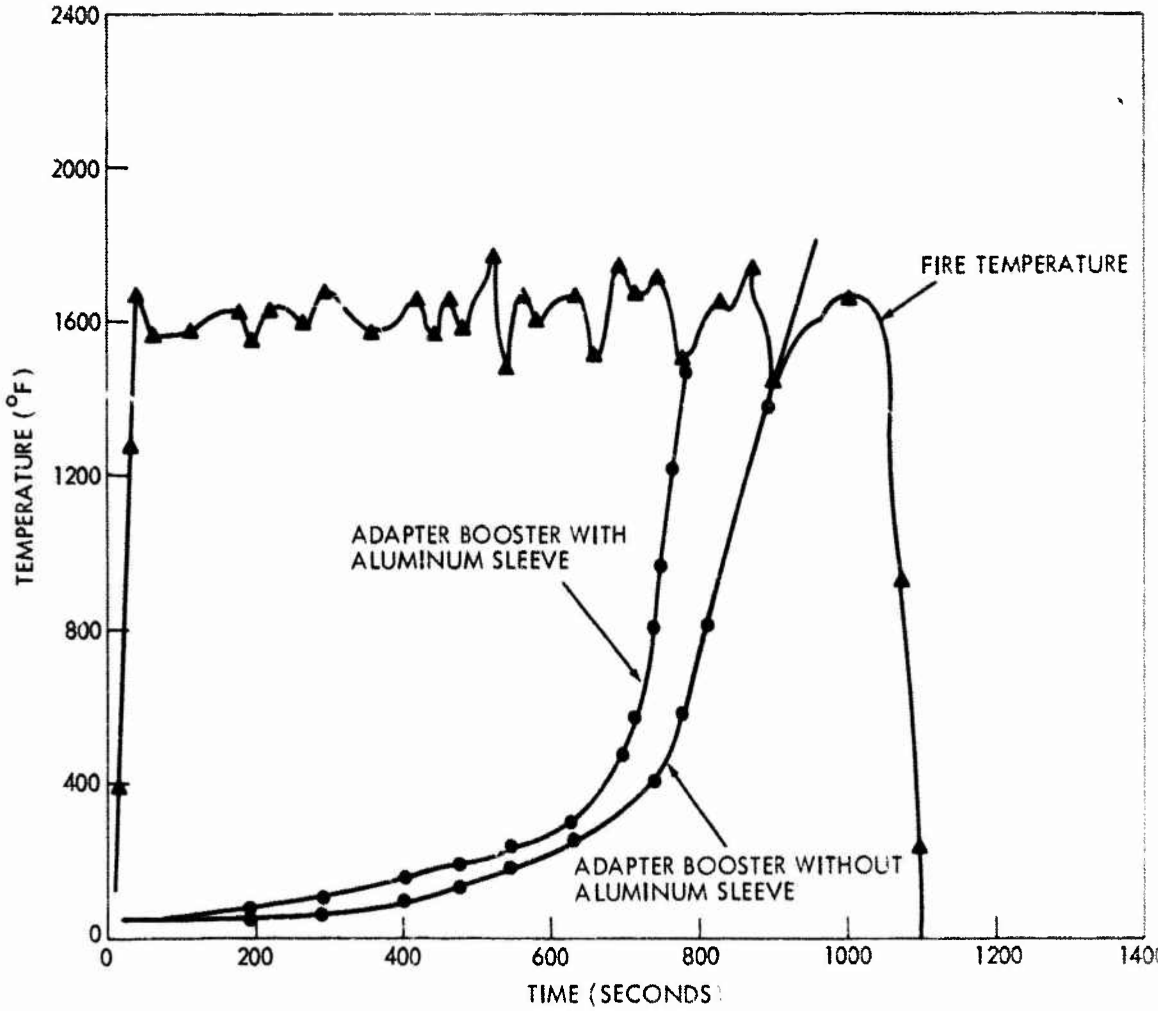


FIG. 46 TIME TEMPERATURE PLOT OF FUZE TEST NO 11

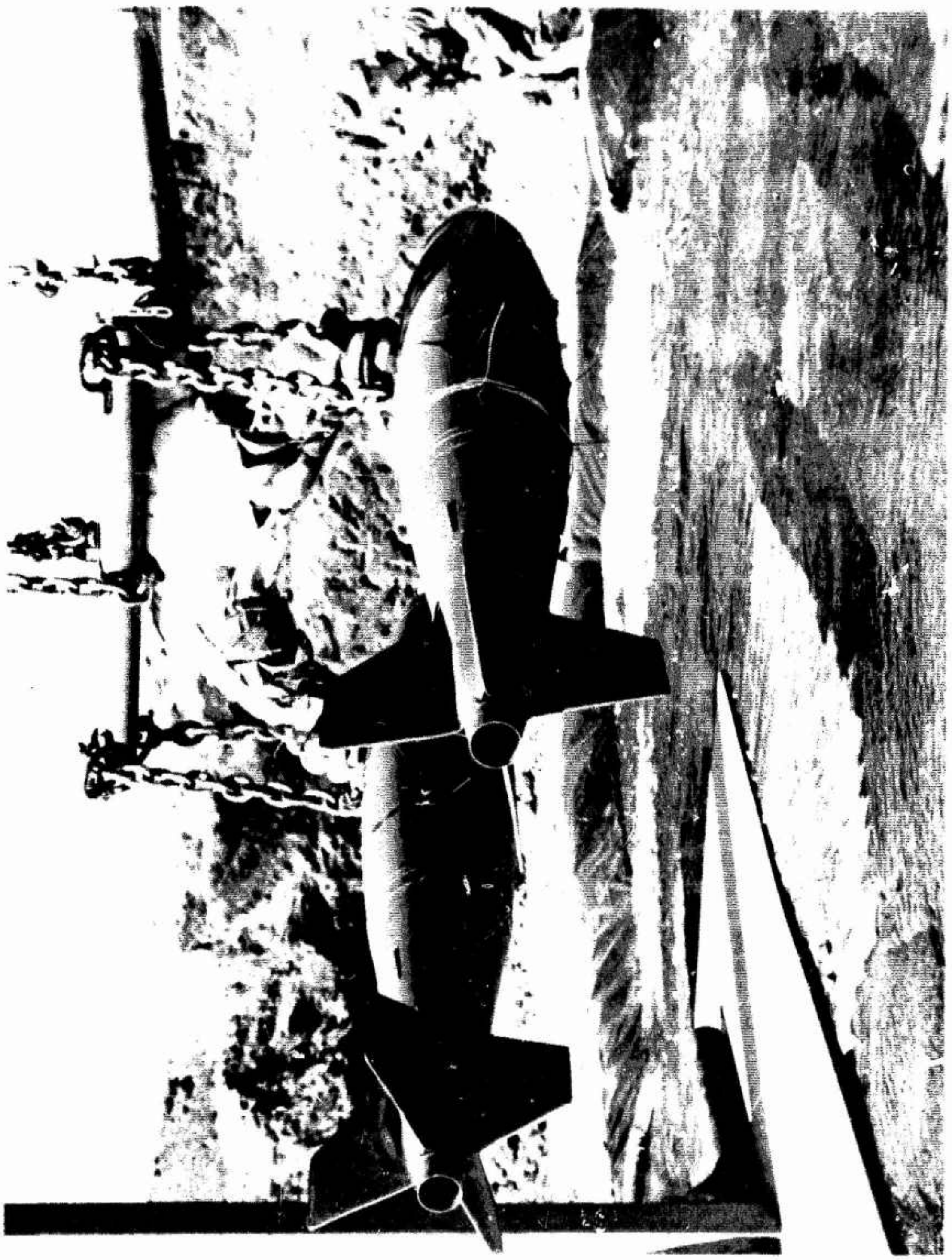


FIG. 47 TEST SET UP BEFORE TEST NO. 12

FIG. 48 TEST SET UP AFTER FUZE TEST NO. 12

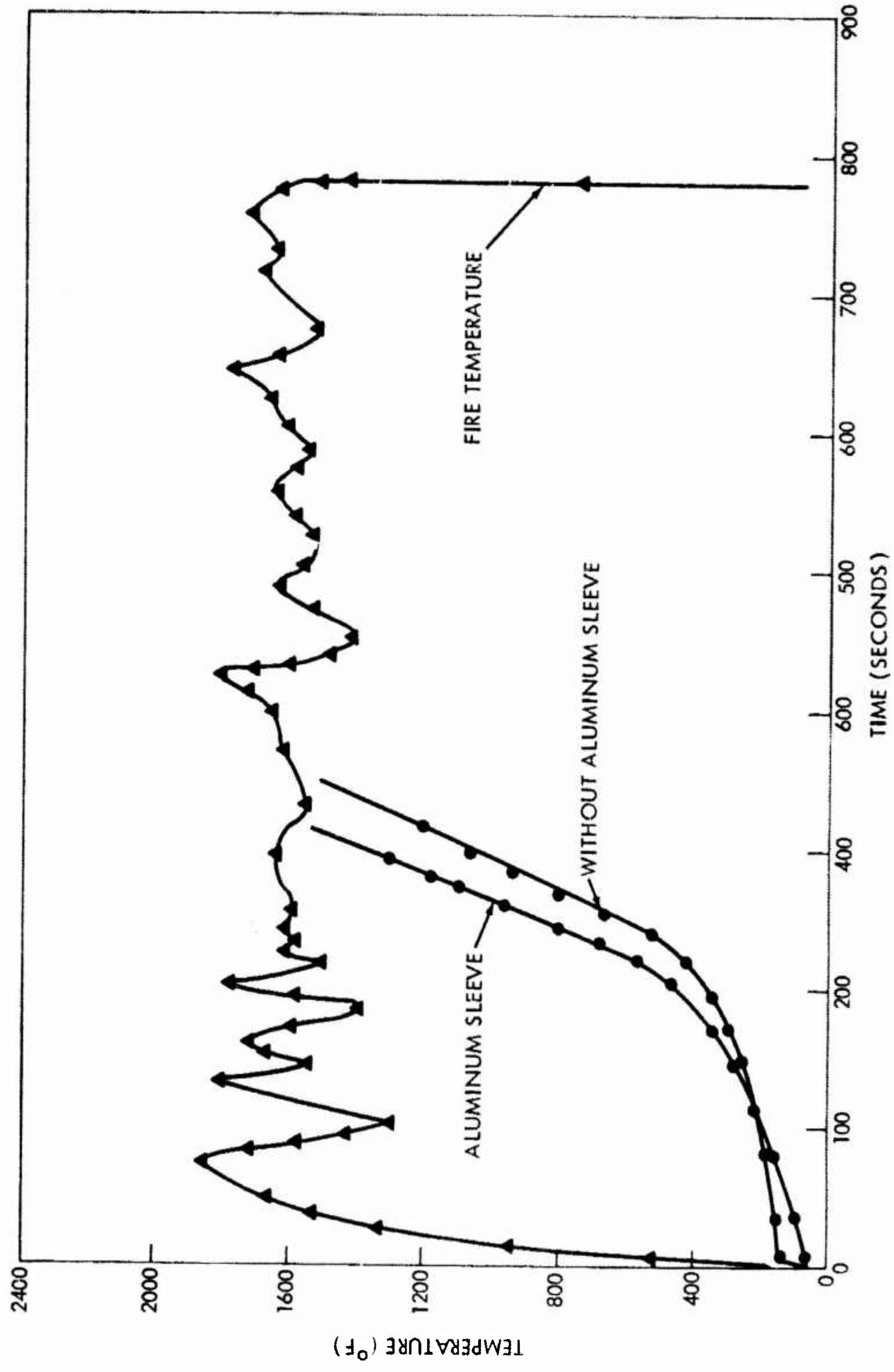


FIG. 49 TIME TEMPERATURE PLOT OF FUZE TEST NO 12

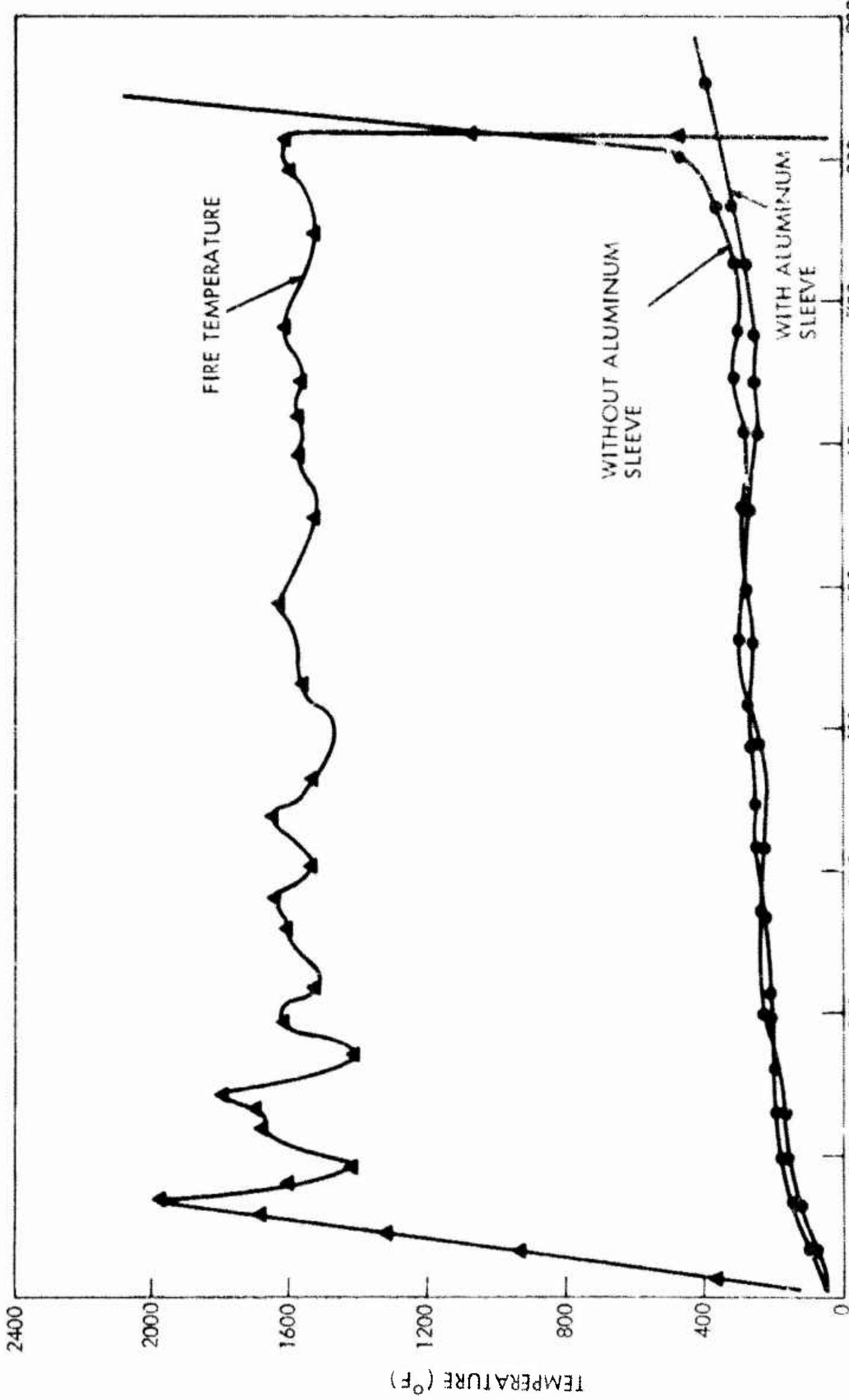


FIG. 50 TIME TEMPERATURE PLOT OF FUZE TEST NO 13

From these three experiments it appears that in calm wind conditions the open adapter booster compares favorably with a fixed Fuze M904E2 in cook-off resistance. However, in strong wind conditions, when the flame is directed into the booster cavity the cook-off times are relatively short, and the adapter booster must be fixed.

Fuze Test No. 14

The top, bottom and inner surface of one of the aluminum sleeves of the M148 Adapter Booster were coated with intumescent paint in addition to the top of the closing disc and the face of the adapter ring. This was assembled into an inert loaded bomb and tested in a fire with a companion bomb containing a standard M148 Adapter Booster. It was hoped that when the flame impinged on the inner surface of the adapter booster, the paint would intumesce and thereby retard the heat transfer to the adapter booster explosive. The wind velocity was ten knots. The grenades were ignited, the wind shifted 180° in direction and the flame was not directed into the open adapter booster. As a result, the standard adapter booster deflagrated in twelve minutes fifteen seconds (735 seconds). The fixed adapter booster deflagrated in thirteen minutes forty-five seconds (825 seconds). The time temperature curves of this test are shown in Figure 51.

Due to the uncertainity in conducting wind tests in this manner, it was decided to conduct the test utilizing a wind generator whereby both the wind velocity and direction could be carefully controlled. A three hundred horsepower electric motor with a variable pitch propeller blade was used (Figure 52). The motor was driven by a portable generator, see Figure 53, capable of delivering 1000 amperes for short intervals. A great deal of current was initially needed to start the engine. Once the engine was in operation, the current dropped to approximately 100 Amperes. A study was then made to determine the air flow patterns at different heights and distances from the center line of the propeller. Figure 54 shows the results of this study. The ordinate of the plot indicates the vertical distance along the center line of the propeller in feet. The abscissa represents the air velocity in miles per hour. A family of curves are shown in the figure ranging from distances of 20 ft to 50 ft. Due to the nature of the open adapter booster test and the hazards associated with the test set-up, it was decided to place the wind generator fifty feet from the test pit.

An experimental thermocouple grid shown in Figure 55 was then set up in order to determine the proper height the bombs should be positioned above the fuel level in order to get maximum temperatures. The results of this test are shown in Figures 56, 57, 58, 59 and 60. From the temperature time plots it was determined that the bombs should be positioned one foot above the level of the burning fuel to achieve the highest temperatures. The computer

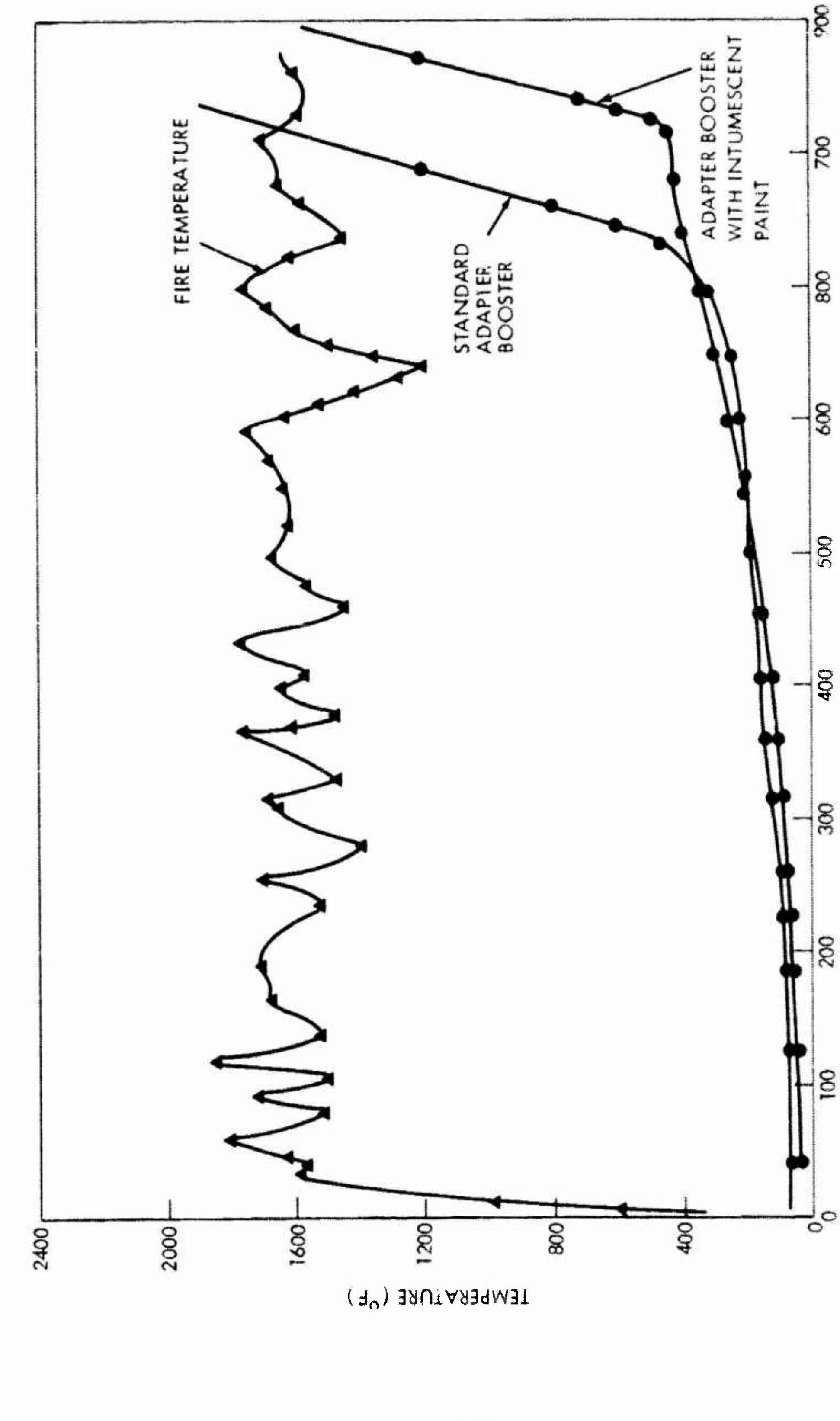


FIG. 51 TIME TEMPERATURE PLOT OF FUZE TEST NO 14

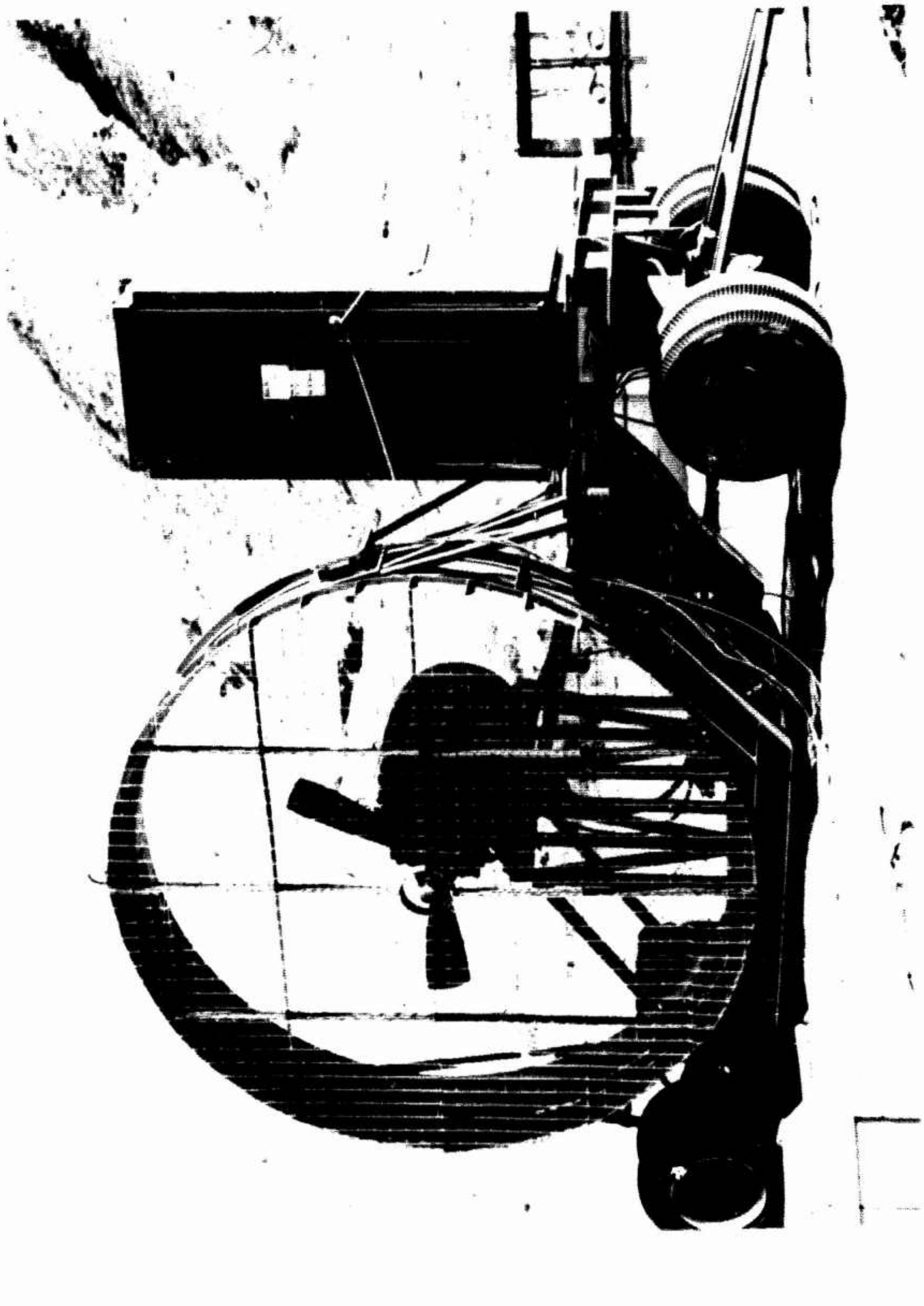


FIG. 52 WIND GENERATOR

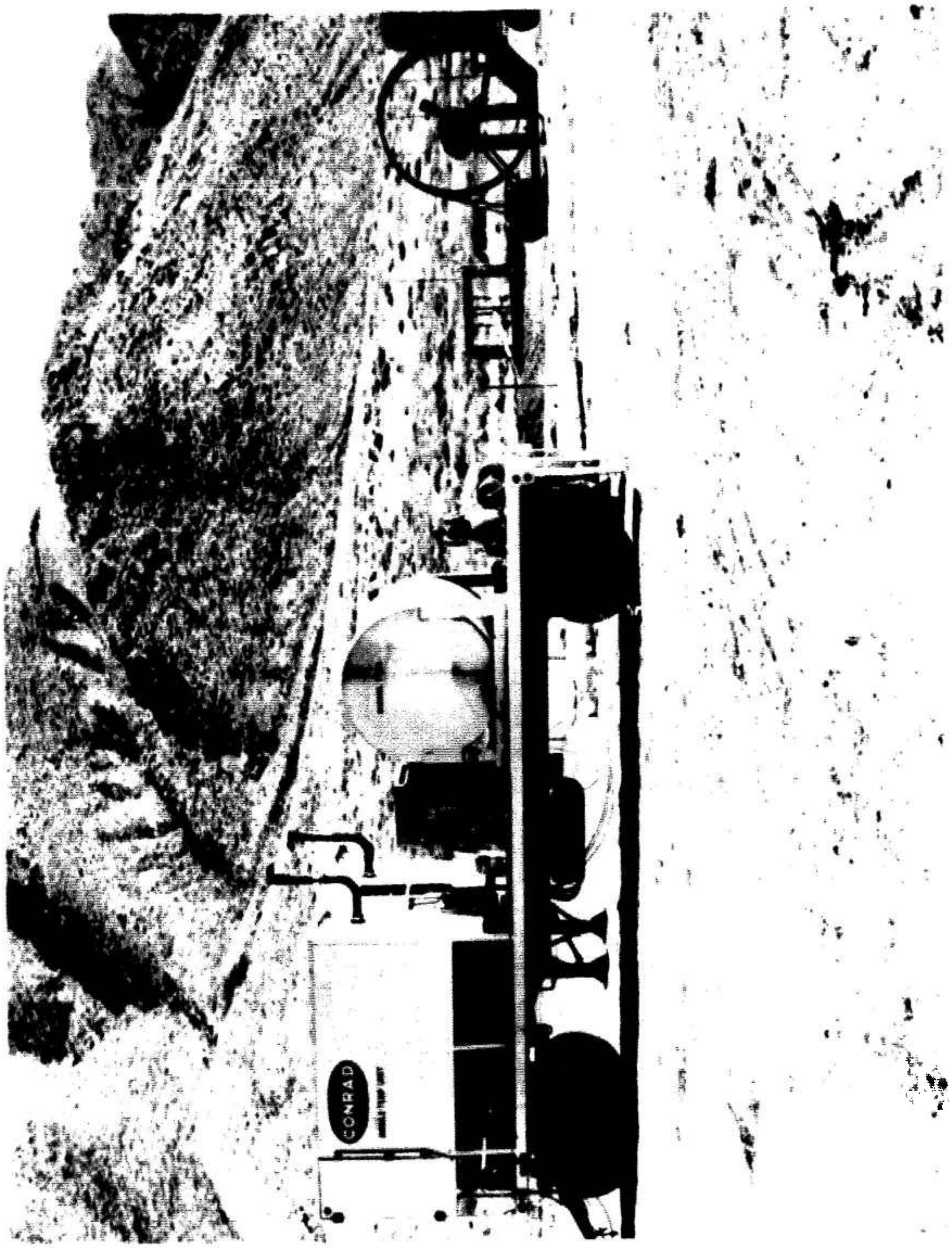


FIG. 53 POWER GENERATOR

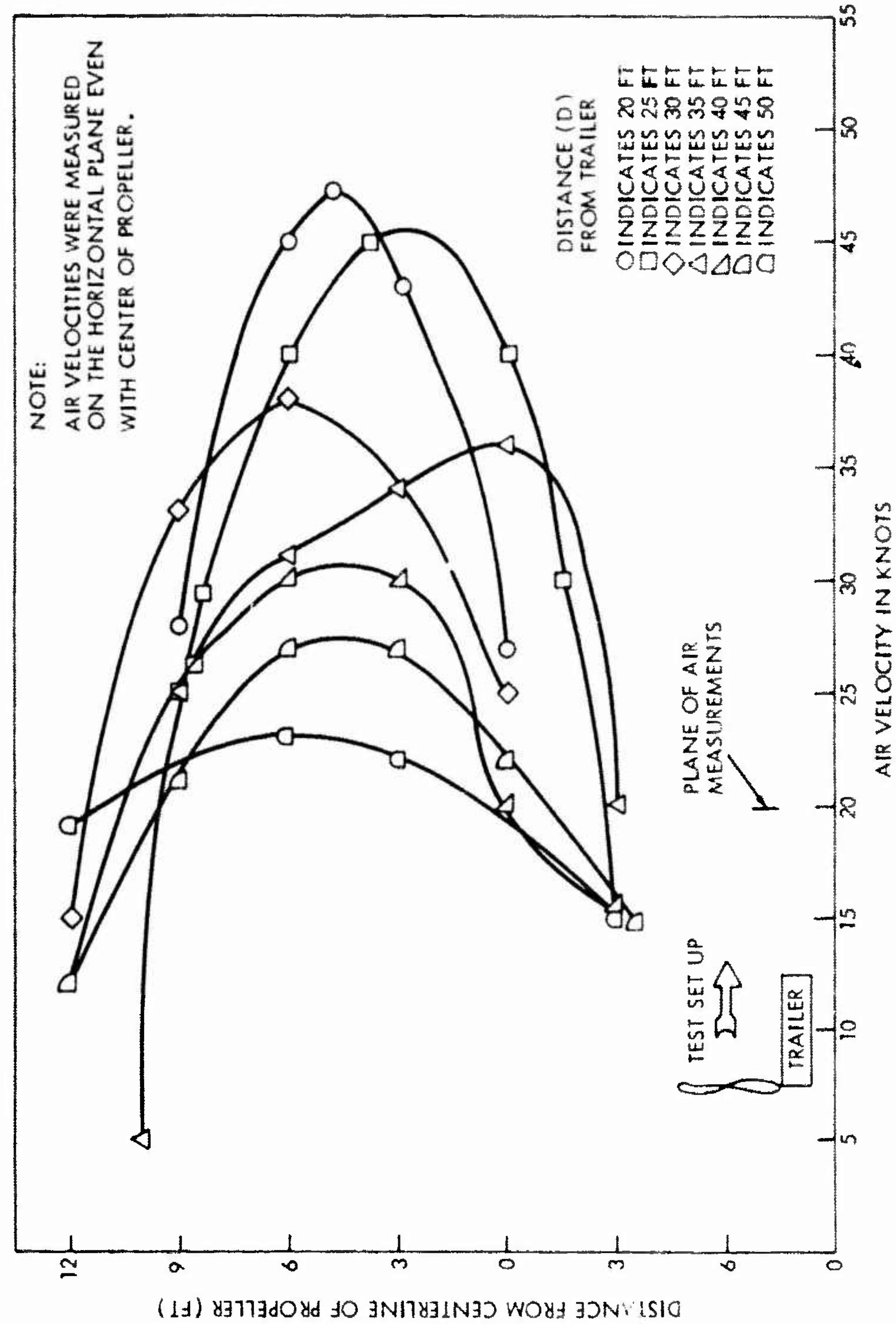


FIG. 54 AIR FLOW PATTERNS FOR 300 H. P. WIND GENERATOR

FIG. 55 EXPERIMENTAL THERMOCOUPLE GRID FOR DETERMINING HOTTEST POINT IN FIRE

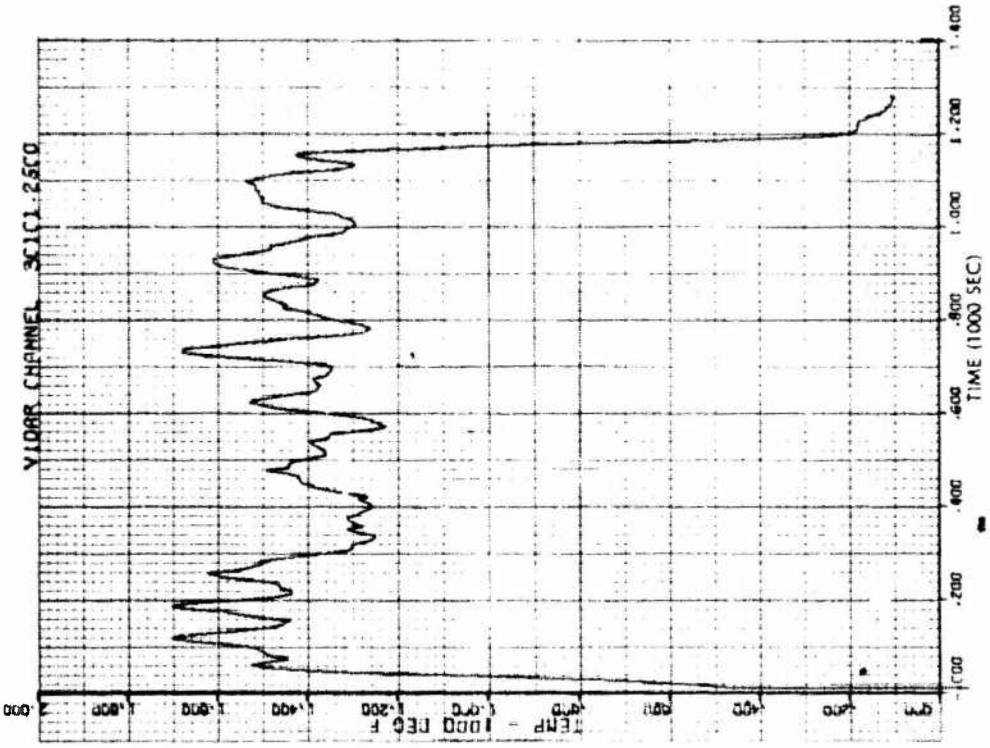


FIG. 56 TIME TEMPERATURE CURVE OF THERMOCOUPLE POSITIONED ONE FOOT ABOVE FUEL LEVEL

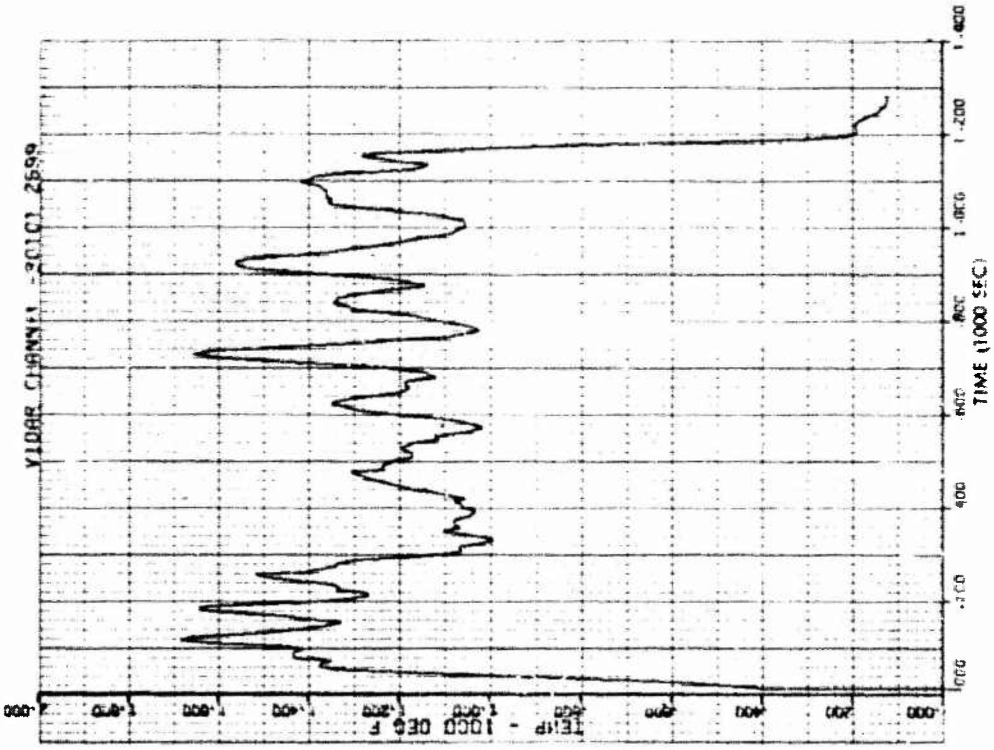


FIG. 57 TIME TEMPERATURE CURVE OF THERMOCOUPLE POSITIONED TWO FEET ABOVE FUEL LEVEL

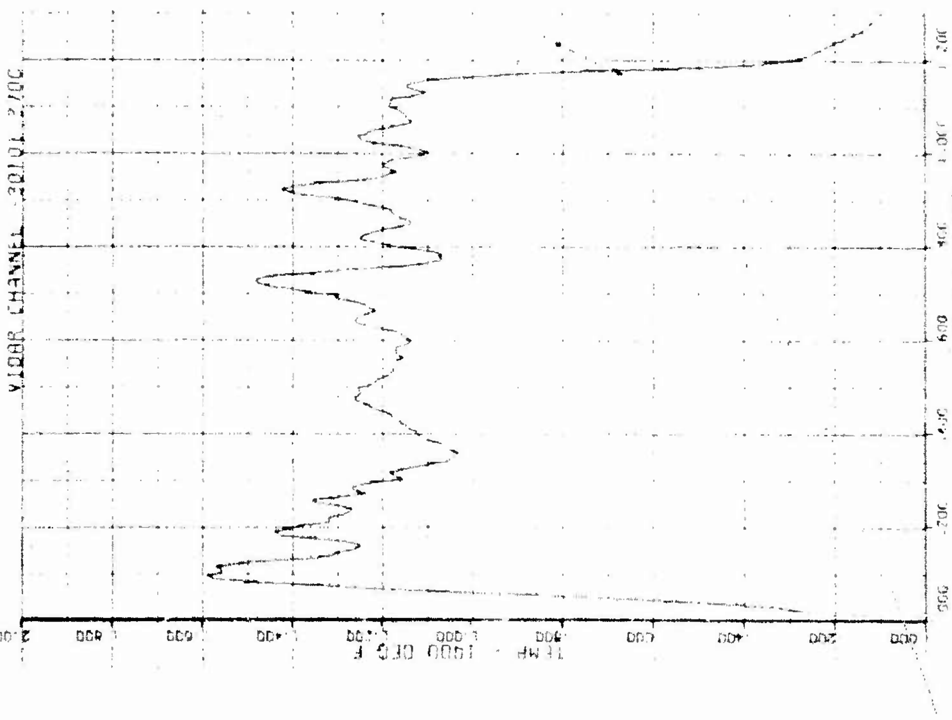


FIG. 58 TIME TEMPERATURE CURVE OF THERMOCOUPLE POSITIONED THREE FEET ABOVE FUEL LEVEL

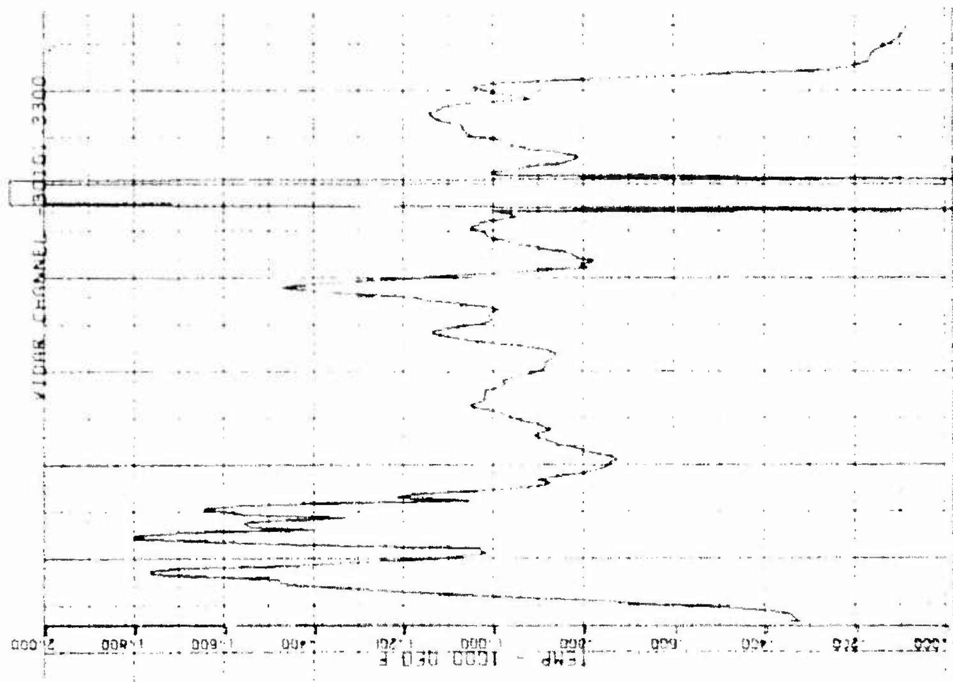


FIG. 59 TIME TEMPERATURE CURVE OF THERMOCOUPLE POSITIONED FOUR FEET ABOVE FUEL LEVEL

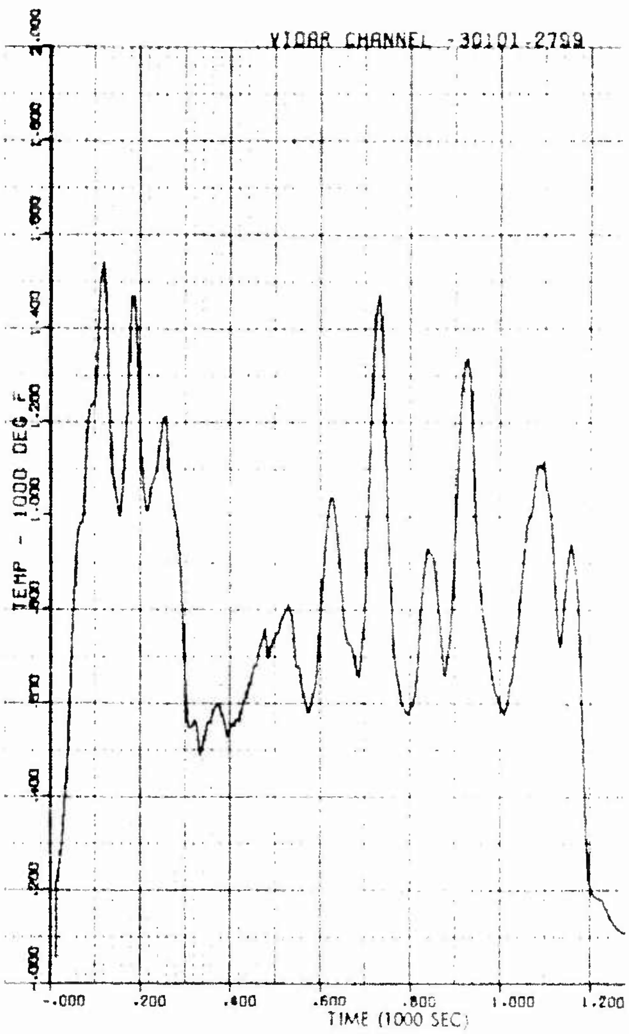


FIG. 60 TIME TEMPERATURE CURVE OF THERMOCOUPLE POSITIONED FIVE FEET ABOVE FUEL LEVEL

plots shown in the above figures were made possible at this stage in the program by coupling an incremental tape recorder (magnetic tape) with the data acquisition system. The program for the plot routine is shown in Appendix B.

Fuze Test No. 15

Fuze tests 15 and 16 were performed with the air of the wind generator. Fuze Test No. 15 consisted of suspending two inert concrete filled thermally protected bombs outfitted identically with live adapter boosters. The adapter boosters were both thermally fixed in the following manner. The inner surface and top surface of the aluminum sleeve were coated with 30 mils of an NOL formulated intumescent paint called Insunol (See NAVAIR Dwg. No. 599AS105). Four mils of a polyurethane overcoat were used to seal the paint. A steel disc 2.50" in outside diameter and 29 mils thick was painted on both sides with a 30 mil thickness of intumescent paint and the overcoat. The face of the adapter ring was also painted with 30 mils of intumescent paint and a 4 mil overcoat. The steel disc with the intumescent paint was placed on top of the closing disc of the adapter booster, the painted aluminum sleeve reinserted and held in a place with the painted adapter ring. A parts arrangement of an Adapter Booster M148 incorporating the intumescent paint fixes is shown on Figure 61. The coating of the steel adapter ring with the intumescent paint was done to retard the heat transfer to the booster of the Fuze M904E2. It was hoped, however, that the intumescent paint would also extend the cook-off times of the adapter booster. Two identical Mk 82 Bombs were suspended one foot above the surface of the fuel level; they were placed at the extreme end of the pit facing the wind generator. Figure 62 shows the experimental set up. Eight thermocouples were installed in each bomb. Four thermocouples were placed at the interface of the tetryl and felt disc, and four were placed in the booster adapter ring hole. Four thermocouples were symmetrically placed around each bomb to record fire temperature. Seven inches of fuel (JP-4) on top of one inch of water was placed in the pit. The wind velocity was measured at 24 knots at the level of the adapter booster. The fire burned after ignition for 18 minutes (1080 seconds) and then went out. Two hundred fifty-two seconds later one of the adapter boosters deflagrated. Two hundred eighty-six seconds later the second bomb deflagrated. The temperature profiles of the thermocouples in contact with the explosive are shown in Figures 63 and 64. The fire temperature thermocouple is shown in Figure 65. The recorder was shut after 1360 seconds. The fire temperatures are consistent with the temperatures determined in the calibration shot. The flames were directed into the booster cavity as determined by visual observations and 16mm color films.

Fuze Test No. 16

Fuze Test No. 16 was set up to test an alternate fix if the intumescent paint fix failed on environmental storage or if an

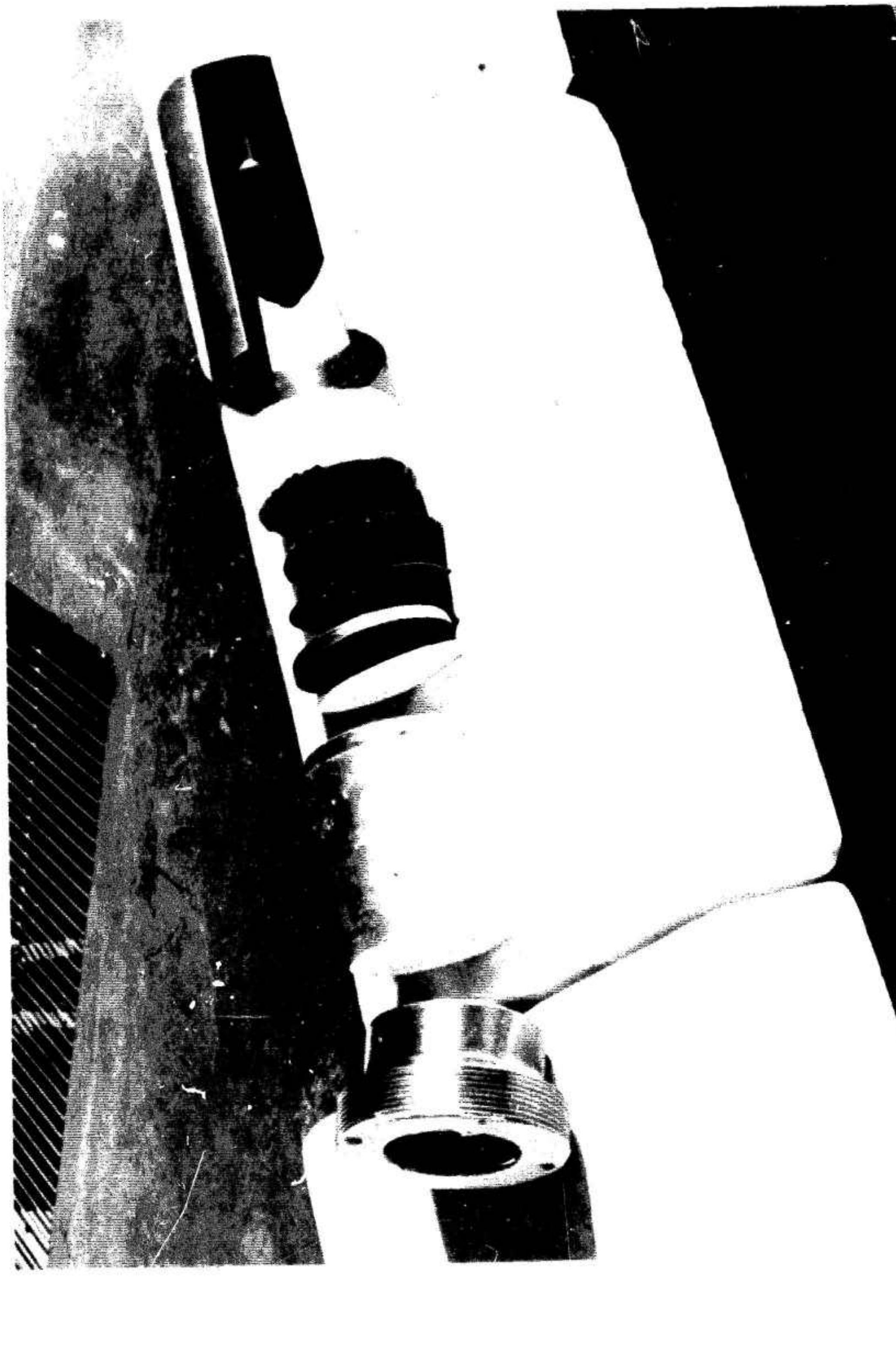


FIG. 61 PARTS ARRANGEMENT, M148 ADAPTER BOOSTER MODIFIED TO INCORPORATE INTUMESCENT PAINT FIX

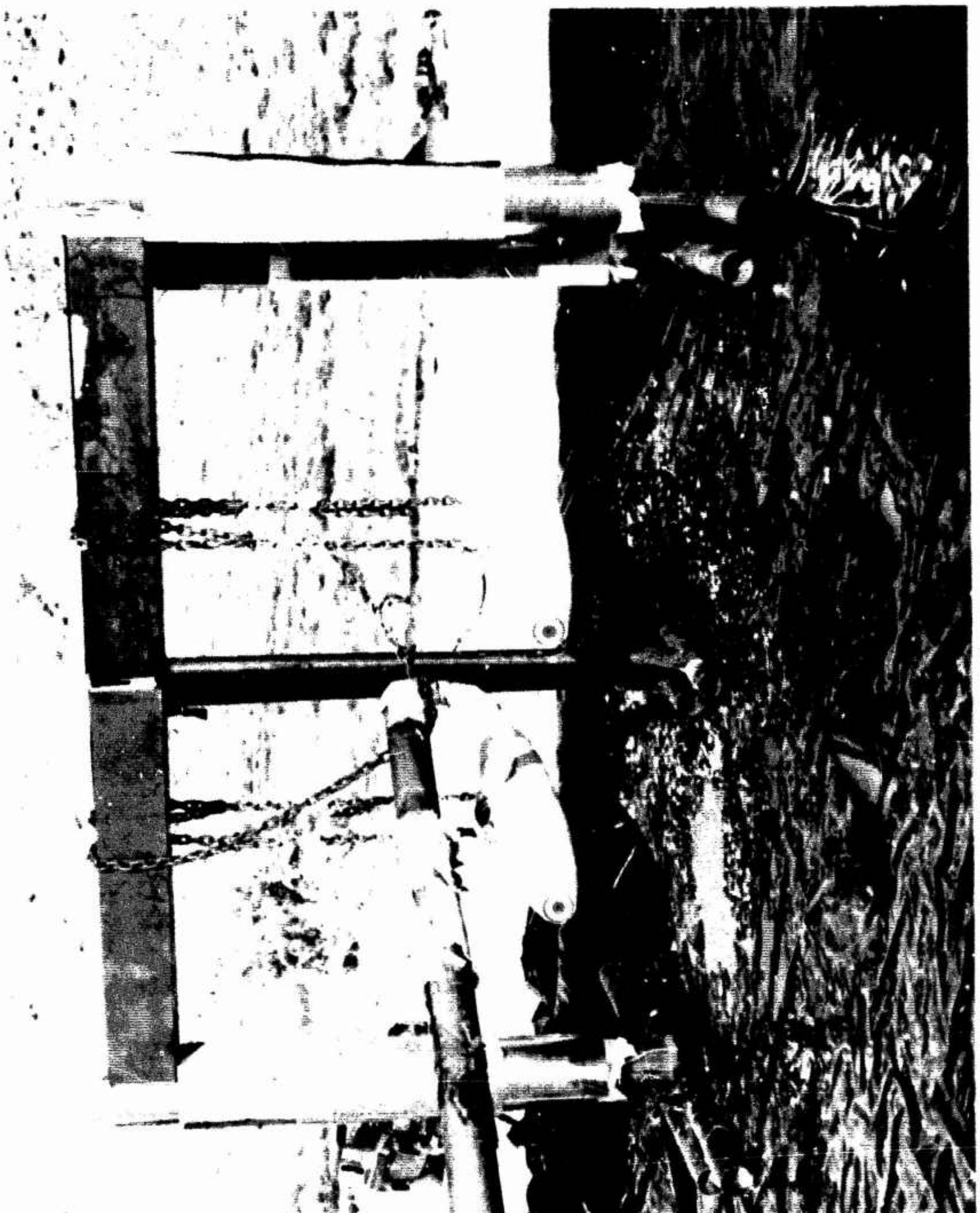


FIG. 62 TEST CONFIGURATION FOR FUZE TEST NO. 15

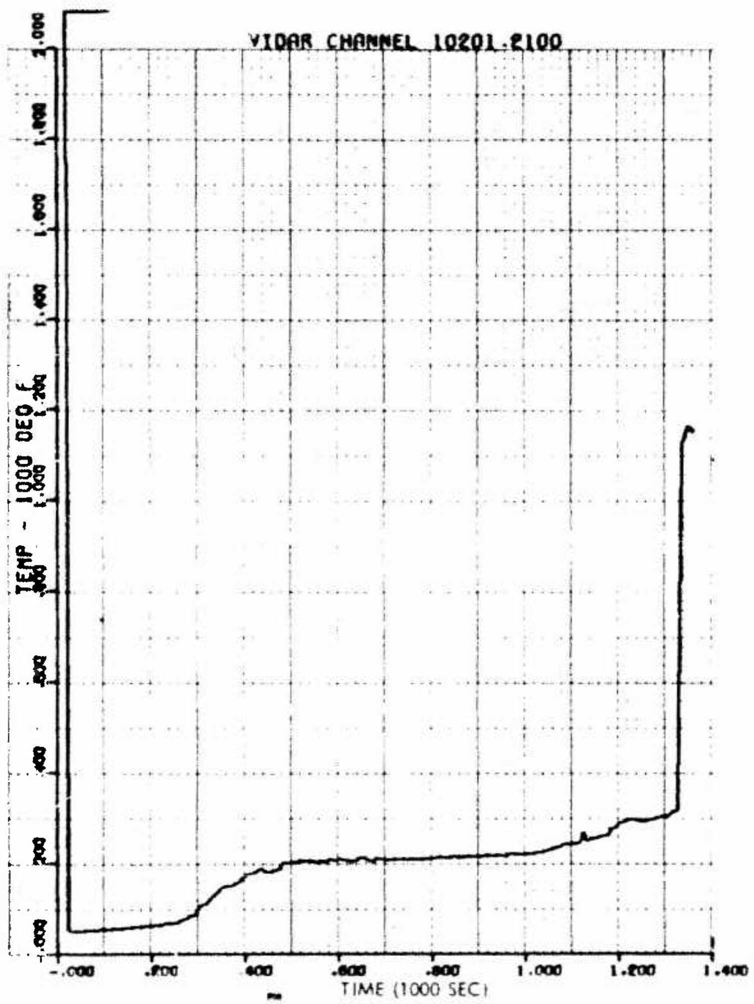


FIG. 63 TIME TEMPERATURE CURVE FOR FUZE TEST NO. 15

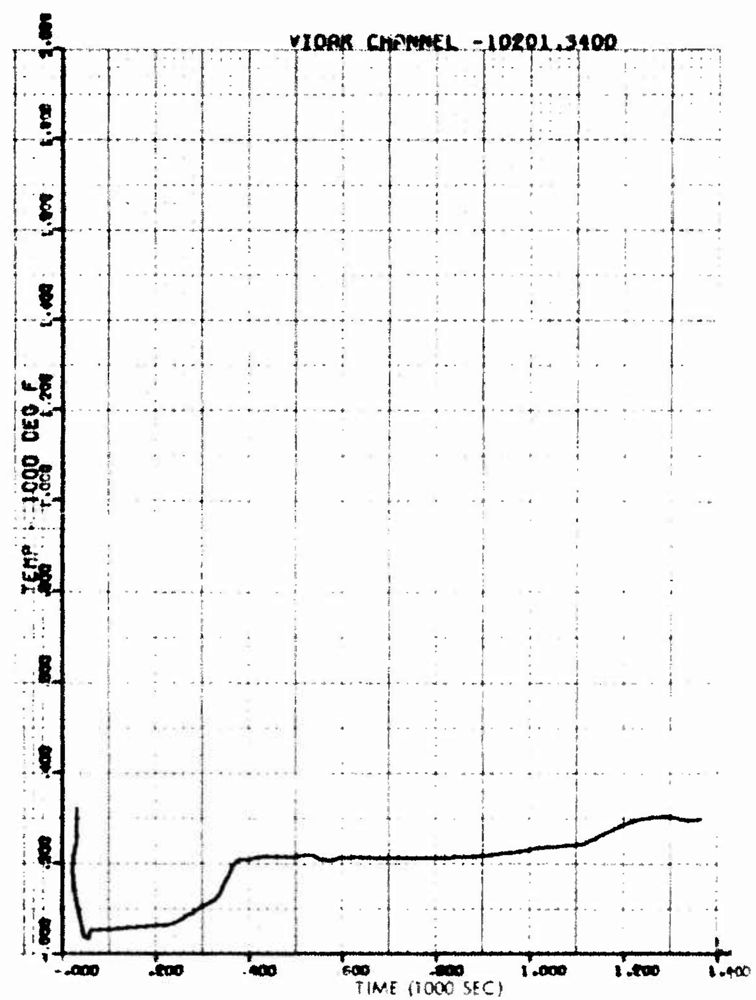


FIG. 64 TIME TEMPERATURE CURVE FOR FUZE TEST NO. 15

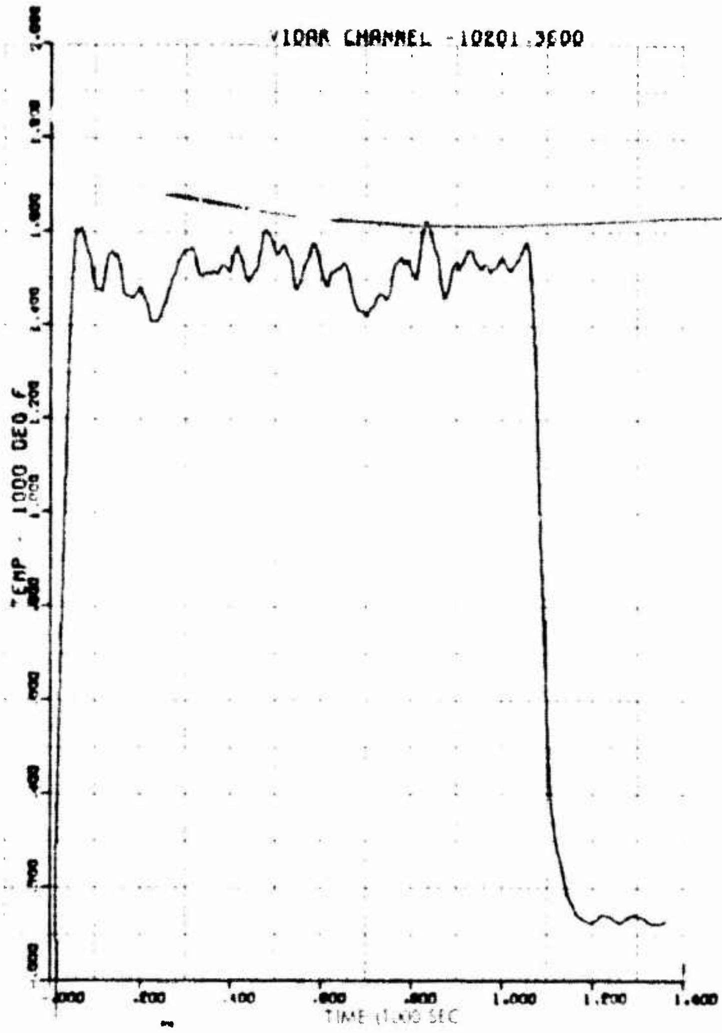


FIG. 65 PROFILE OF FIRE TEMPERATURE FOR FUZE TEST NO. 15

incompatibility with the fuze fix developed.

There were a number of proposed approaches in addition to intumescent paint to increase the cook-off time of the open adapter booster. These are listed below:

1. Insulative disc and washer
2. Spring and cup
3. Phenolic fuze liner
4. Heat resistant cover

These various ideas were actually represented by hardware for further consideration, with a phenolic disc and washer being the first choice for further test. However, before any tests could be accomplished we were directed by the Naval Missile Center, as program manager, to test a .1" thickness of disc and washer of Candidate No. 10 at the exclusion of all others. Figure 66 is a photograph of the disc and washer. The dimensions of the disc are 2.50" in outside diameter and .100" thick and it goes on top of the steel closing disc. The washer is 2.625" O.D. x 1.625" I.D. x .100" thick and it goes between the adapter ring and sleeve. The sleeve was machined to a height of 2.903" to accomodate this increased thickness of material.

Two thermally protected inert concrete loaded bombs were fitted with thermally fixed live adapter boosters containing the Candidate No. 10 disc and washer. The bombs were suspended one foot above seven inches of the JP-4 fuel. The wind generator was turned on and the wind velocity was measured as 32 knots of which twenty knots was from the wind generator and 12 knots from natural wind which was blowing in the westerly direction.

Seventeen minutes and twenty seconds (1040 seconds) after the start of the fire the first bomb detonated. The nose of the bomb was bulged out and expanded, (see Figure 67). The aluminum sleeve was destroyed. At 20 minutes and 42 seconds (1242 seconds), or 202 seconds later, the second bomb deflagrated. The fire temperature thermogram is shown in Figure 68. Again, the average fire temperature is compatible with what we find in the calibration shot. The time temperature response of the thermocouples in contact with the explosive are shown in Figures 69 and 70. We see a flat spot on the thermogram of the thermocouples in contact with the explosive. This indicates that the Candidate No. 10 material may be evolving water keeping the explosive relatively cool. The results of the open booster tests are summarized in Table 19.

From an analysis of the preceding data, both the intumescent paint and the Candidate No. 10 material appear to be thermally acceptable as a fix for the open adapter booster. The intumescent paint, however, was chosen as the primary fix because of the cheap material costs and its easy application. Since only one adapter

FIG. 66 DISC AND WASHER MADE FROM CANDIDATE NO. 10 MATERIAL

FIG. 67 PHOTOGRAPH OF AREA AFTER FUZE TEST NO. 16

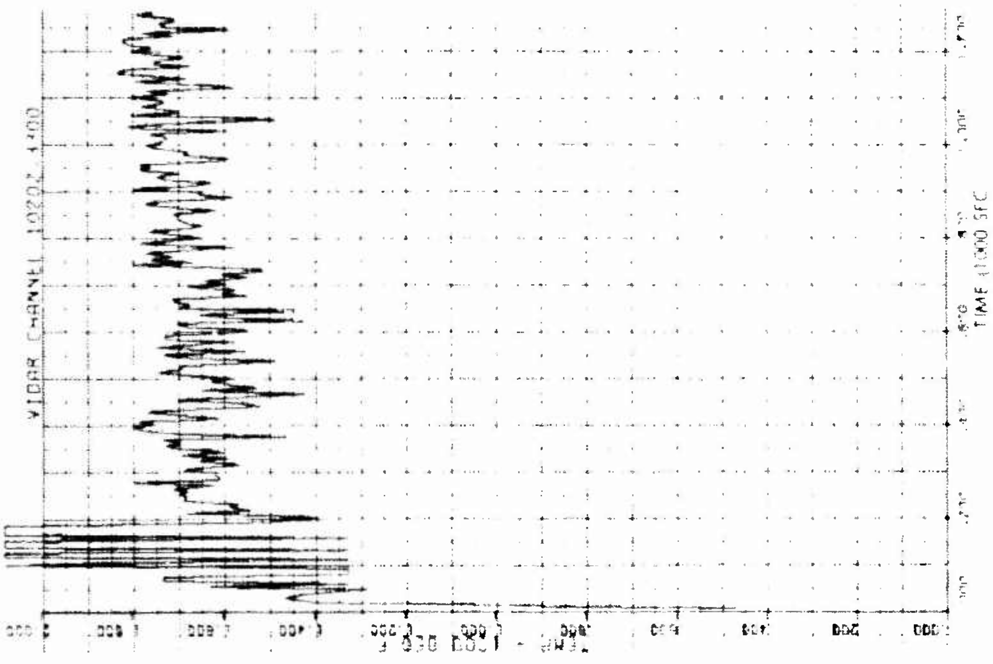


FIG. 68 FIRE TEMPERATURE THEMOGRAM OF FUZE TEST NO. 16

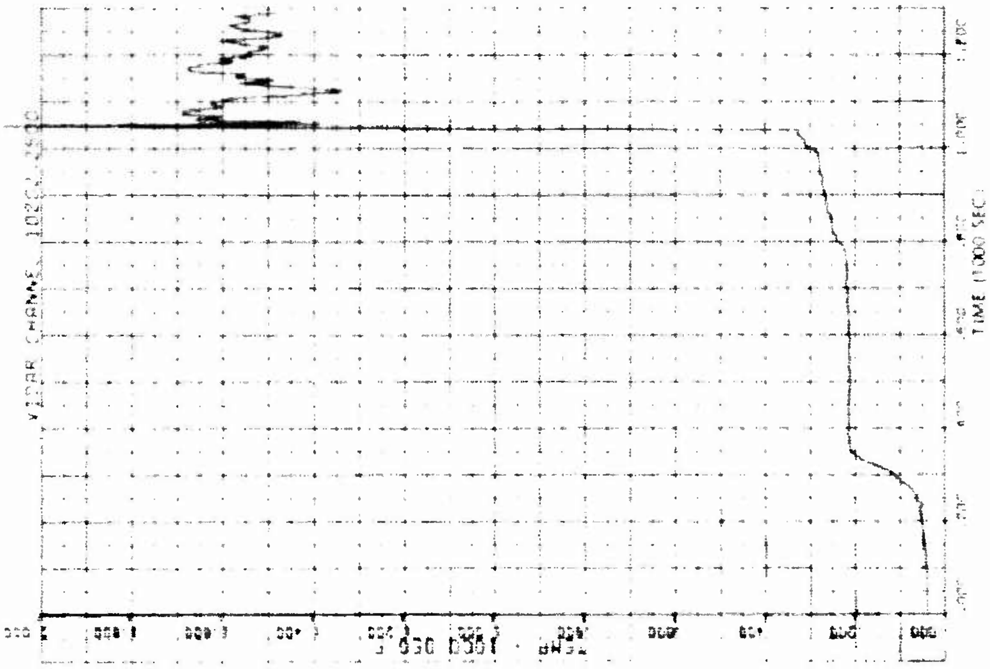


FIG. 69 M148 ADAPTER BOOSTER THERMOGRAM OF FUZE TEST NO. 16

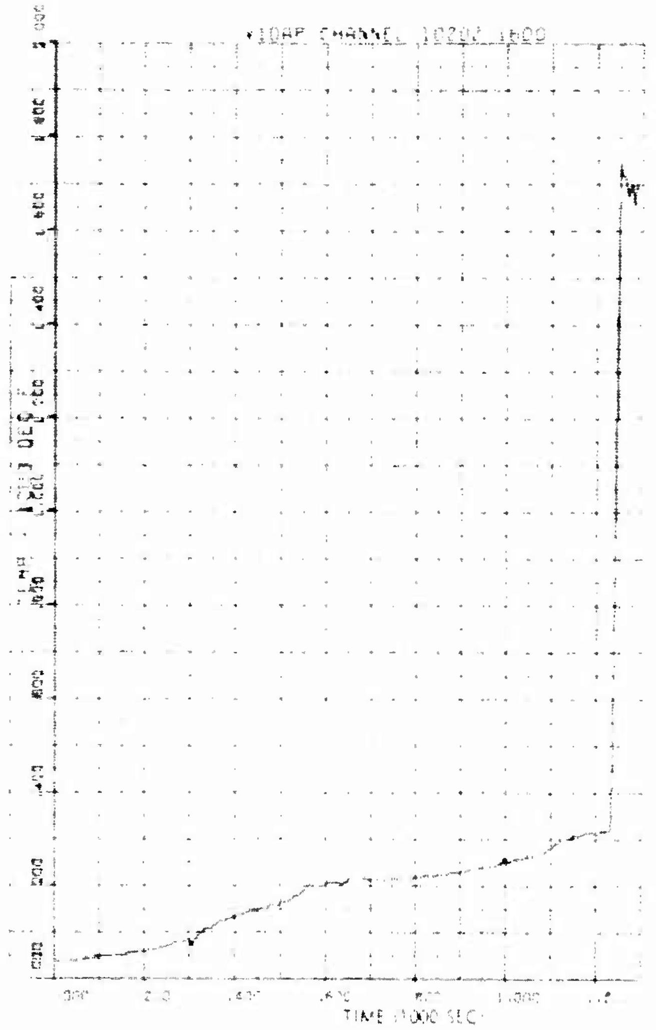


FIG. 70 M148 ADAPTER BOOSTER THERMOGRAM OF FUZE TEST NO. 16

Table 19

Cook-Off Results on M148 (T45E7) Open Adapter Boosters Mounted in Thermally Protected Mk 82 Bombs

Fuze Test No.	Open Adapter Booster Configuration	Mk 82 Bomb Contents	Reaction Time/Sec.	Kind of Reaction	Wind Conditions
11	Live - with aluminum sleeve	Sand Filled	703	Deflagration	0-3 knots
11	Live - without aluminum sleeve	" "	792	Deflagration	0-3 knots
12	Live - with aluminum sleeve. Suspended 24 in. above fuel.	" "	226	Explosion	10 knots in cavity
12	Live - without aluminum sleeve. Suspended 24 in. above fuel.	" "	240	Explosion	10 knots in cavity
13	Live - with aluminum sleeve. Suspended 26 in. above fuel.	" "	810 (Fire died out in 810 sec.)	Explosion	4 knots
13	Live - without aluminum sleeve. Suspended 26 in. above fuel.	" "	1050 (Fire died out in 810 sec.)	Explosion	4 knots
14	Live - painted inside and face with Insunol.	" "	825 (Fire direction changed)	Deflagration	10 knots (wind shifted)
14	Live - painted inside and face with Insunol	" "	735 (Fire direction changed)	Deflagration	10 knots (wind shifted)

Table 19 (Con't.)

Fuze Test No.	Open Adapter Booster Configuration	Mk 82 Bomb Contents	Reaction Time/Sec.	Kind of Reaction	Wind Conditions
15	Live - painted inside and disc and face with Insunol.	Concrete Filled	1332 (Fire died out in 1080 sec.)	Deflagration	24 knots (wind generator)
15	Same as above	"	1518 (Fire died out in 1080 sec.)	Deflagration	24 knots (wind generator)
16	Live - painted face and disc and washer	"	1040	Detonation	32 knots (wind generator)
16	Same as above	"	1242	Deflagration	32 knots (wind generator)

booster fix was to be evaluated the final choice was to be based on a combined test with the thermally protected Fuze M904E2. This combined fix would determine if the fuze was compatible with the adapter booster fix.

In order to obtain the most effective Nose Fuze M904E2 protective covering the best insulators from the small scale fire tests were fabricated into protective sleeves. The castable sleeves were fabricated by using two piece aluminum molds shown in Figures 71 and 72. The center core was fabricated out of Teflon in order to act as a mold release. The entire assembly was also sprayed with teflon mold release agent to facilitate easy removal from the molds. A jig was also made so that the holes for the window, screw and spring release of the Fuze M904E2 could be drilled in the proper place. This jig is shown in Figure 73.

Fuze Test No. 17

Based on experience gained on cook-off testing and in the interest of obtaining more information for each fire, at less cost per bomb, it was proposed to test four bombs in each fire. Such a plan was possible because of the ability through data acquisition equipment to determine the origin of reaction and information from a large number of sensors. Fuze Test No. 17 consisted of four inert sand filled bombs containing ¼" high melting hot melt but not painted on the exterior surface with intumescent paint. All the adapter boosters were sand filled and inert. Three bombs contained live fixed Fuzes M904E2 and one bomb contained an inert unfixed Fuze M904E2 which served as a reference calorimeter. The live nose fuzes were equipped with sleeves fabricated out of Candidates No. 14, No. 8, and No. 1 materials. These sleeves were bonded on the fuze with Silastic 737.

Unfortunately, a different insulation procured for the protection of the thermocouples coming out of the bombs and into the reference junction was inadequate. Although 1000°F thermocouple wire was used the thermocouples shorted out after three minutes engulfment in the fire. It was therefore impossible to ascertain which shot cooked-off and when and only the total cook-off times as determined from the sound of reactions were obtained.

Six minutes (360 seconds) after the start of the fire the first fuze deflagrated. One hundred twenty seconds later the second fuze deflagrated and sixty seconds later the third fuze deflagrated. From inductive reasoning it is believed that the bomb outfitted with the fuze with Candidate No. 14 sleeve went in 360 seconds, the Candidate No. 8 material reacting next in 460 seconds and Candidate No. 1 material in 540 seconds. The shorter cook-off times of the Candidate No. 1 material, than was experienced previously, (see Table 18), was attributed to heat transfer through the front and sides of the thermally unprotected bombs. Therefore all future experiments were performed with thermally protected bombs fixed on the exterior with intumescent paint and the interior with high

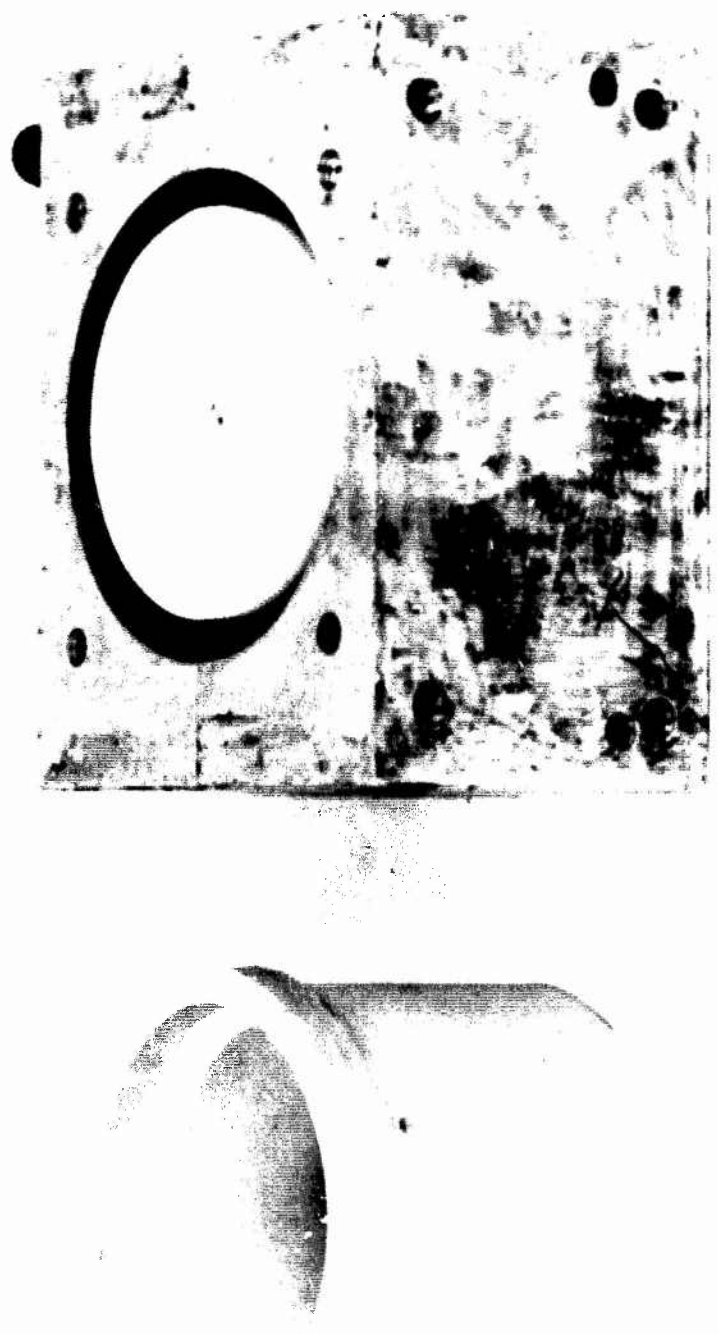


FIG. 71 MOLD NO. 1 FOR PROTECTIVE FUZE COVERING

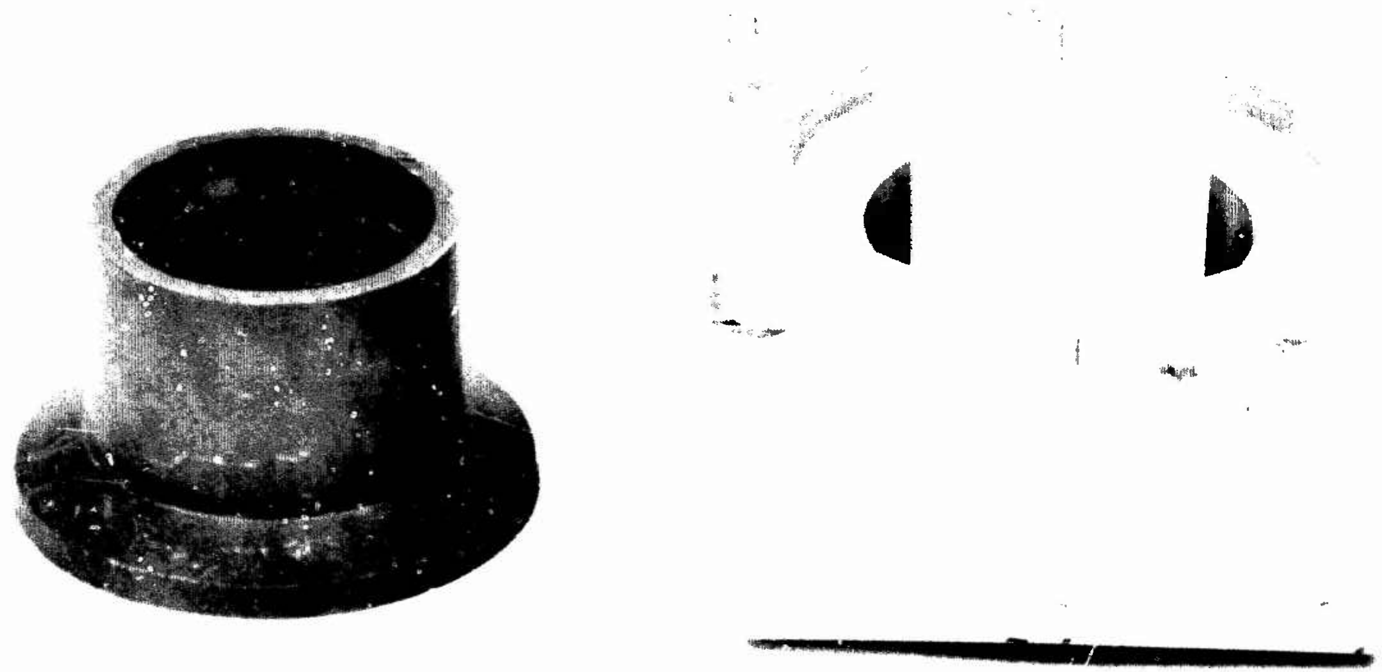


FIG. 72 MOLD NO. 2 FOR PROTECTIVE FUZE COVERING

FIG. [illegible] JIG FOR DRILLING HOLES IN PROTECTIVE COVERING

melting hot melt.

Fuze Test No. 18

Three of the next best insulators chosen from the small scale tests were fabricated into protective sleeves. The materials chosen for study were Candidates No. 12, Candidate No. 4 and Candidate No. 7. Candidate No. 12 and No. 4 were prepared by a contractor. Candidate No. 7 was procured, cast into a mold and cured at 80°C for one half hour at NOL.

Four thermally protected inert sand filled bombs were suspended three feet above the fuel level as in our previous tests. All bombs contained inert T45E7 Adapter Boosters. Three of the M904E2 Fuzes were fitted with one each of the sleeves and served as our reference calorimeter. The test arrangement is shown on Figure 74. The thermocouple arrangement was the same as in previous tests. In order to simplify the data presentation typical time temperature plots for each nose fuze and adapter booster will be presented.

The fuze outfitted with Candidate No. 12 was the first to cook-off. It deflagrated in nine minutes (540 seconds). Two hundred sixteen seconds later the fuze prepared with the Candidate No. 4 deflagrated. One hundred ninety-two seconds later the fuze prepared with Candidate No. 7 deflagrated mildly. Representative fuze thermograms for each of the fixes are shown in Figure 75. It is to be noted that the cook-off temperature of the fuze is approximately 400°F independent of the protective device on the fuze. Representative thermocouple data are shown for the adapter booster in Figure 76. The intumescent paint on the surface of the adapter booster appeared to be effective in preventing heat from entering the front of the bomb.

Subsequent to this test, the environmental storage tests indicated that the above materials would not survive environmental handling. Therefore Candidates No. 12, No. 4 and No. 7 were disregarded from any future consideration.

Fuze Test No. 19

Fuze Test No. 19 was similar to Fuze Test No. 17. The four materials tested were Candidates No. 14, No. 8, No. 1 and No. 5. All the bombs contained inert T45E7 Adapter Boosters. All the bombs were thermally protected. Three had live fuzes protected with Candidates No. 14, No. 8 and No. 1. The other was an inert fuze protected with Candidate No. 5 material that was included at the request of the NMC, Pt. Mugu representative. The bombs were suspended three feet above 2200 gallons of JP-4 jet fuel and ignited by means of thermite grenades. All of the fuzes deflagrated mildly. The fuze with Candidate No. 14 sleeve deflagrated in eight minutes fifty seconds (530 seconds). The fuze with Candidate No. 8 sleeve deflagrated in eight minutes fifty-eight seconds (538 seconds) and

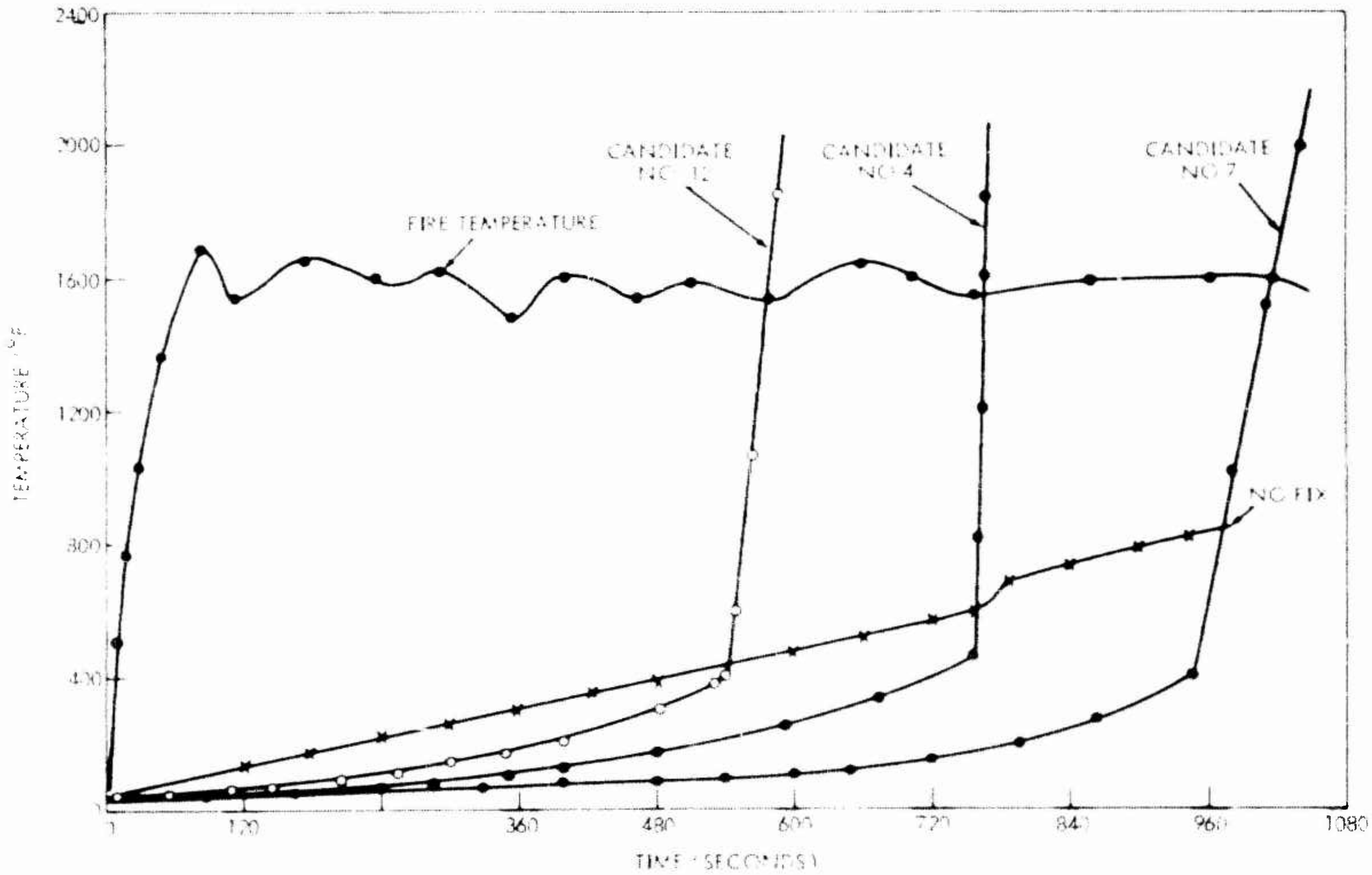


FIG. 75 THERMOGRAMS OF FUZE THERMOCOUPLES FOR FUZE TEST NO. 18

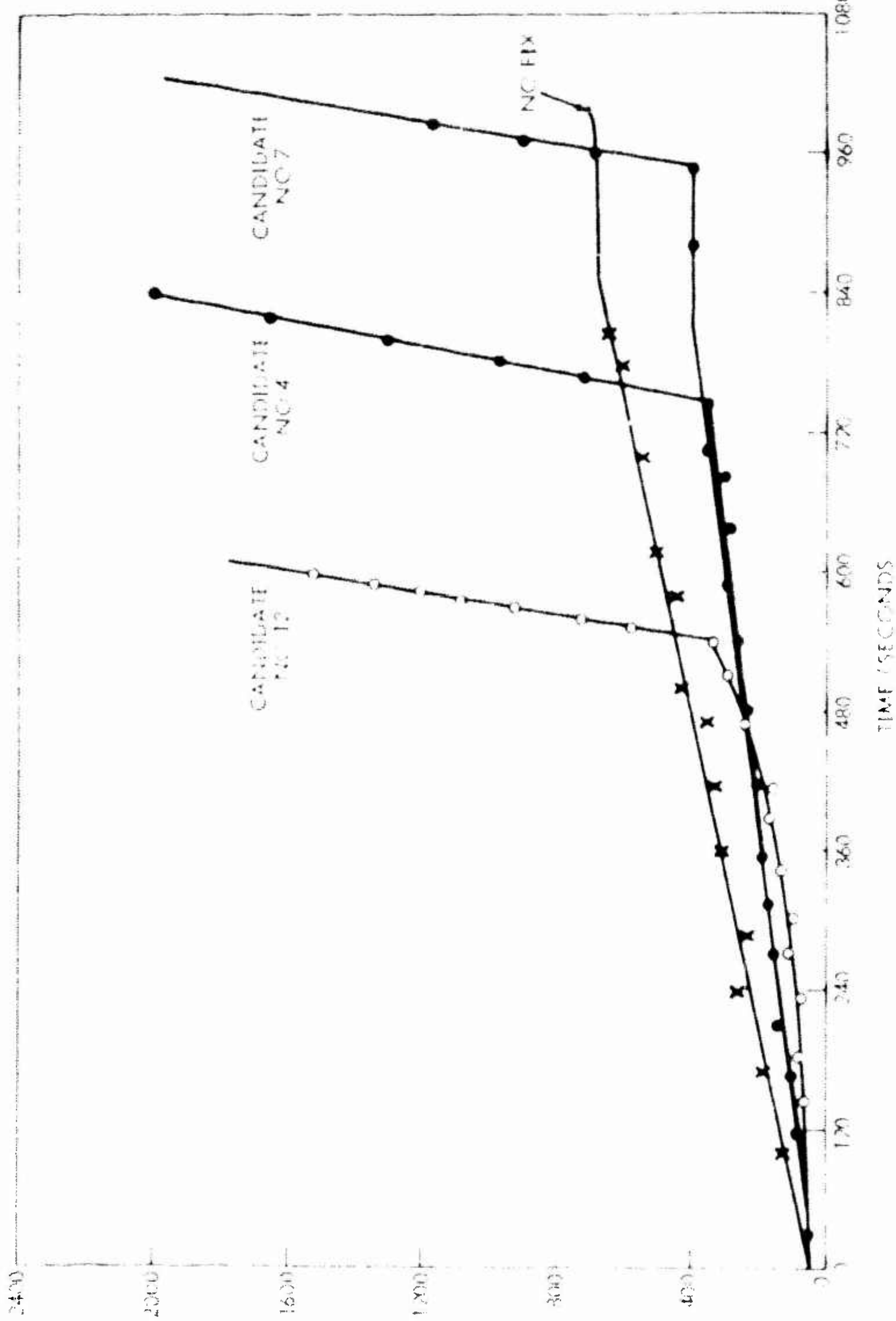


FIG. 76 THERMOGRAMS OF ADAPTER BOOSTER THERMOCOUPLES FOR FUZE TEST NO 18

the fuze with Candidate No. 1 sleeve cooked-off in nine minutes fifty-eight seconds (598 seconds). It was estimated that had the fuze with Candidate No. 5 sleeve been loaded cook-off would have occurred in nine minutes fifty seconds (590 seconds). The fire temperature plot and fuze plots are shown in Figure 77. The temperatures on the Adapter Booster thermocouples are shown on Figure 78. From these data it is also observed that the fuze protective covering influences the heat transfer to the booster. Because of the poor results of environmental screening of Candidate No. 8 and cost it was eliminated from any future consideration. Candidates No. 14, attractive from a cost point, and Candidate No. 5 were retained for further testing.

Fuze Test No. 20

Four sleeve materials consisting of Candidates No. 5, No. 10, No. 1 and No. 14 were employed in this test. The configurations are shown in Figures 79 and 80. Candidate No. 5 sleeve was fabricated with a lip to cover the face of the adapter ring on the adapter booster. A washer of Candidate No. 1 material (same thickness as sleeve) was cemented to the adapter ring face for test in conjunction with Candidate No. 1 material on the Fuze M904E2. A similar arrangement was made up with Candidate No. 10 material. Candidate No. 14 sleeve has a contour similar to a fuze on an existing Navy weapon. The heavy wall is judged to be necessary for the material to meet the insulation requirements and the projected relatively low material costs makes this choice possible. The base diameter of the truncated cone conforms to the diameter of the bomb at the juncture. The four live Fuzes M904E2 with the above sleeves were assembled into Inert M148 Adapter Boosters and Mk 82 sand filled thermally protected bombs. The Fuze M904E2 with Candidate No. 5 deflagrated in nine minutes twenty seconds (560 seconds), see Figure 81. The fuze with Candidate No. 1 deflagrated in twelve minutes forty seconds (760 seconds), see Figure 82. The fuze with Candidate No. 14 deflagrated in thirteen minutes (780 seconds), see Figure 83. The fuze with Candidate No. 10 sleeve and washer deflagrated in twelve minutes forty seconds (760 seconds), see Figure 84. The Adapter Booster thermograms are shown in Figures 85-88. The fire temperature thermogram is shown in Figure 89. All of the cook-off's resulted in deflagrations. The bombs were completely intact after the fire. Photographs of the set up and a view after the fire are shown in Figures 90 and 91.

Fuze Test No. 21

Fuze Test No. 21 was a repeat of Fuze Test No. 20. The washers prepared from Candidate No. 1 and No. 10 were secured to the Adapter Booster ring face with RTV 737 adhesive.

The fuze protected with the Candidate No. 5 deflagrated in seven minutes twenty seconds (440 seconds). The fuze with Candidate No. 1 deflagrated in twelve minutes (720 seconds). The fuze with Candidate No. 10 sleeve deflagrated in seventeen minutes twenty seconds (1040 seconds) and the fuze with Candidate No. 14 deflagrated

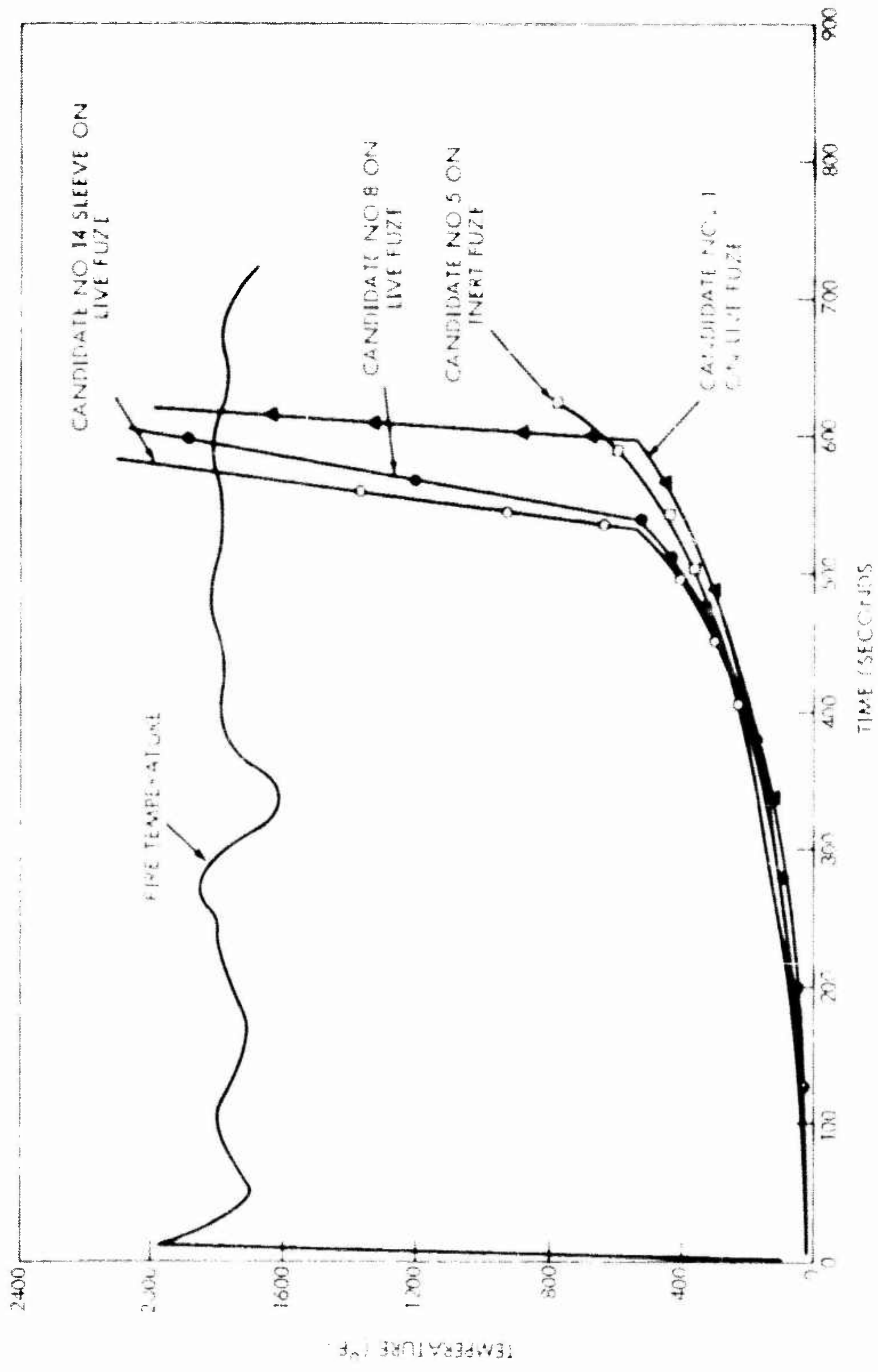


FIG. 37 THERMOGRAM OF THERMOCOUPLES FOR FUZE TEST NO 19

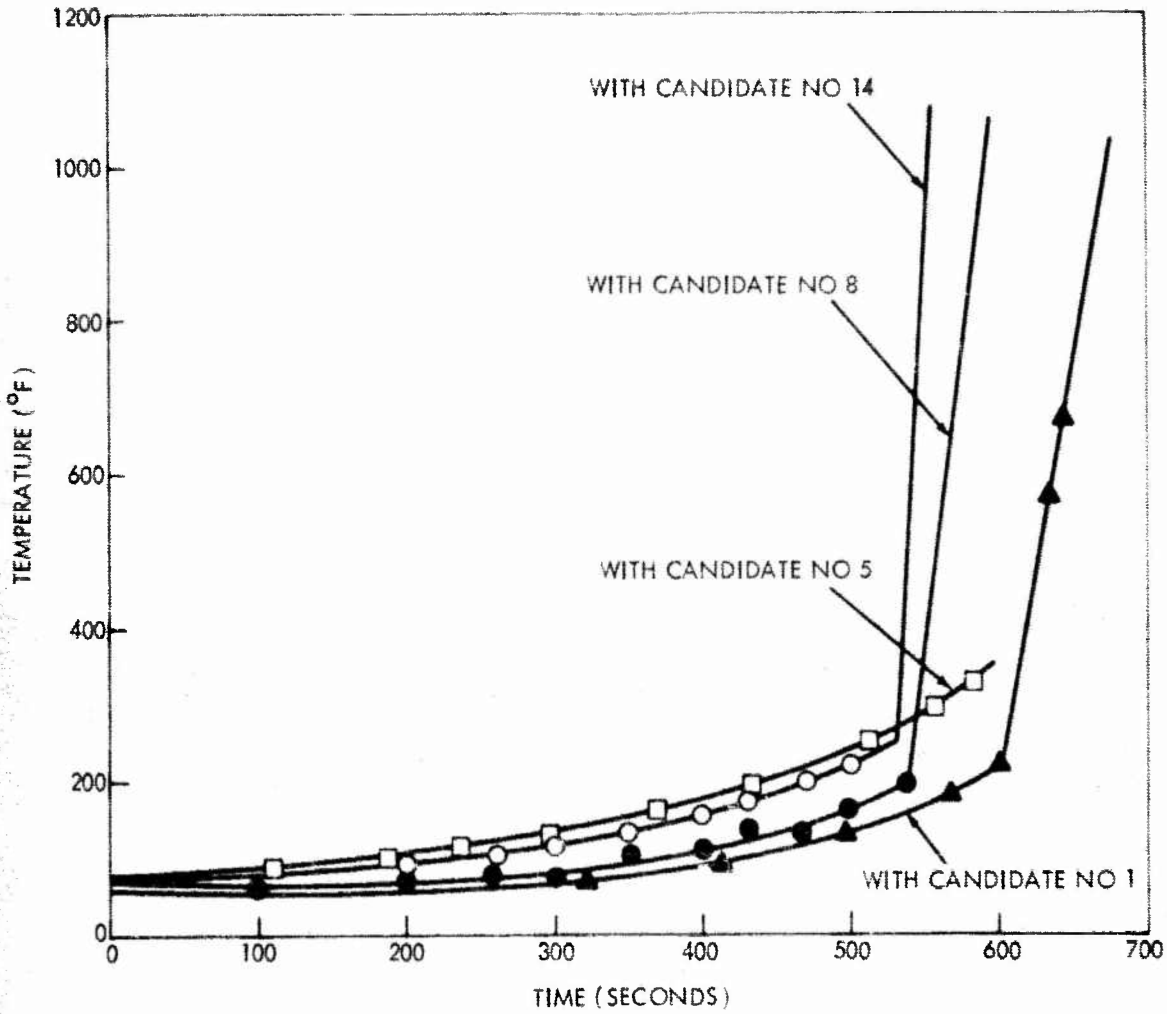


FIG. 78 THERMOGRAMS OF ADAPTER BOOSTER THERMOCOUPLES FOR SHOT NO 19

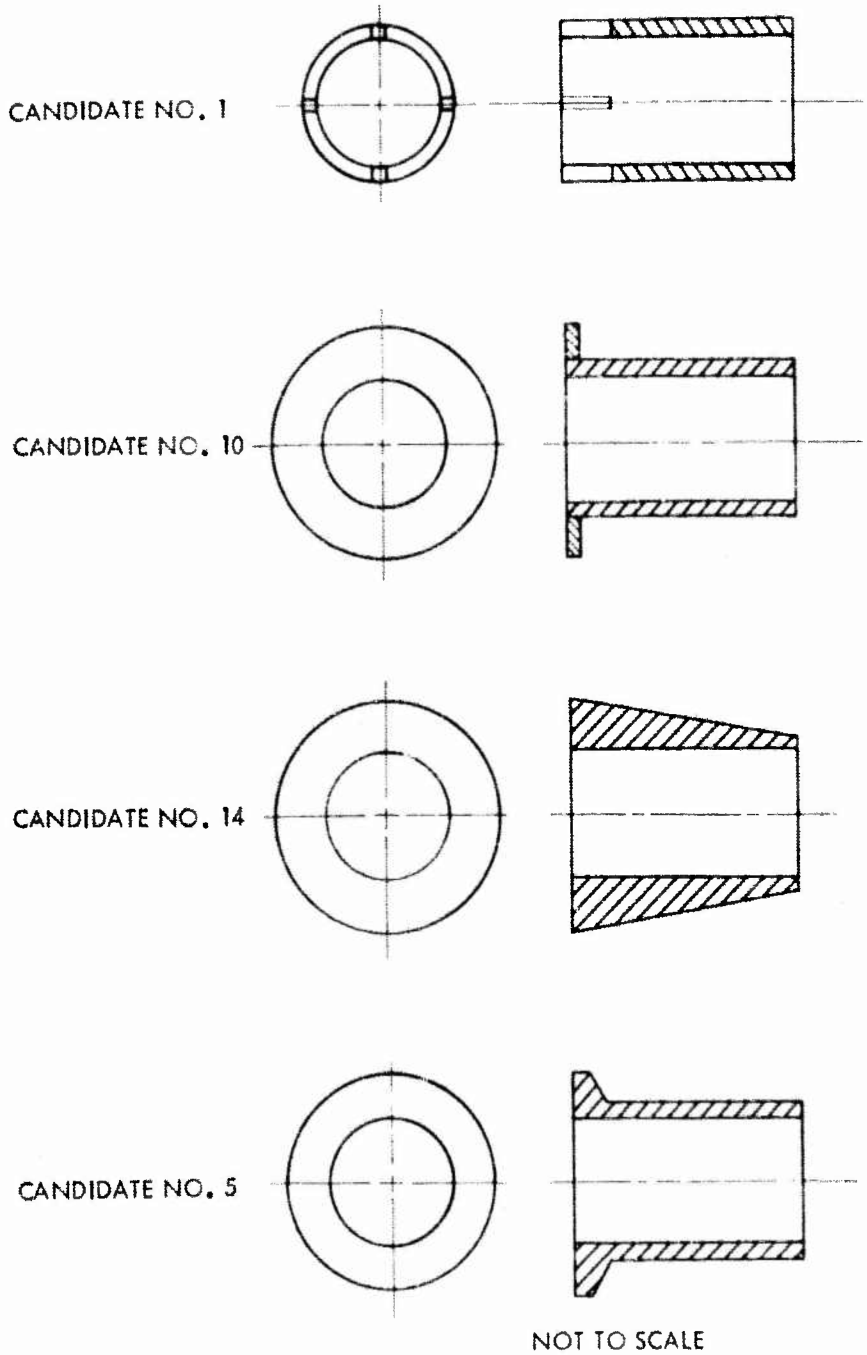


FIG. 79 SCHEMATIC OF CANDIDATE NO 1, NO 10, NO 5 AND NO 14 SLEEVE

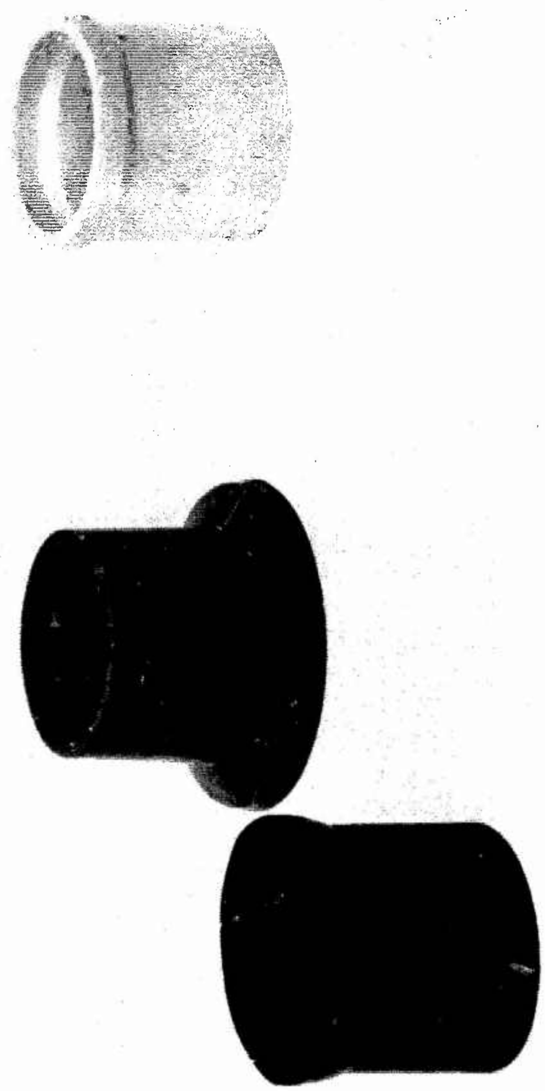


FIG. 80 PHOTOGRAPH OF SLEEVE CANDIDATE NO.1, NO.5, MODIFIED NO.10, AND NO.14

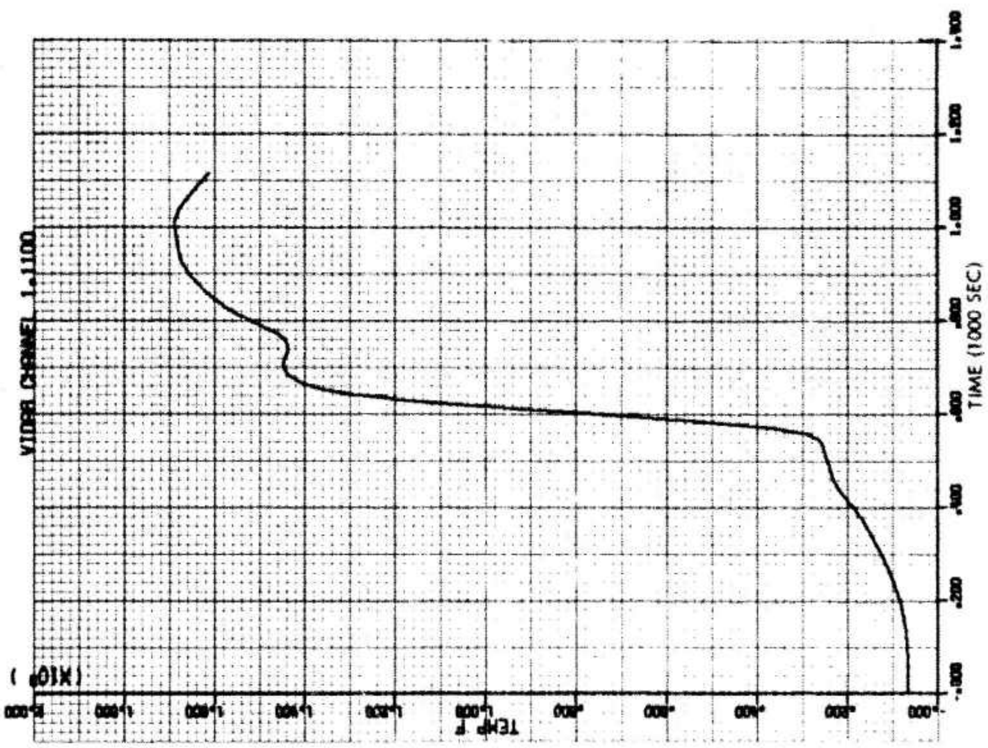


FIG. 81 THERMOGRAM OF FUZE TEST NO. 20 WITH CANDIDATE NO. 5 SLEEVE

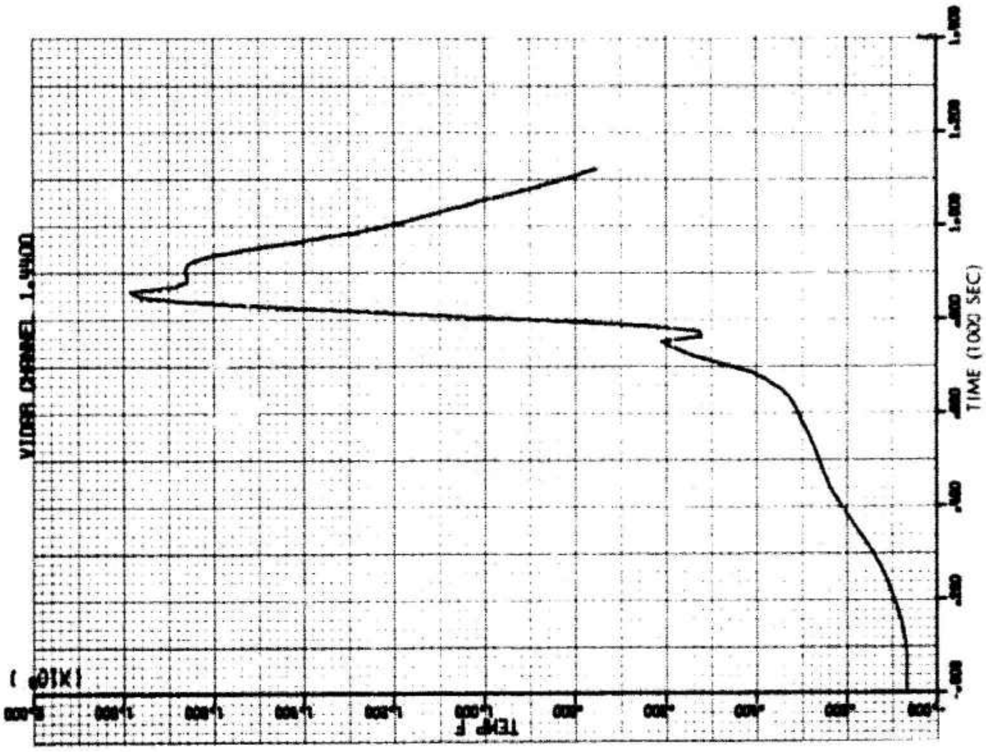


FIG. 82 THERMOGRAM OF FUZE TEST NO. 20 WITH CANDIDATE NO. 1 SLEEVE AND ADAPTER BOOSTER WASHER

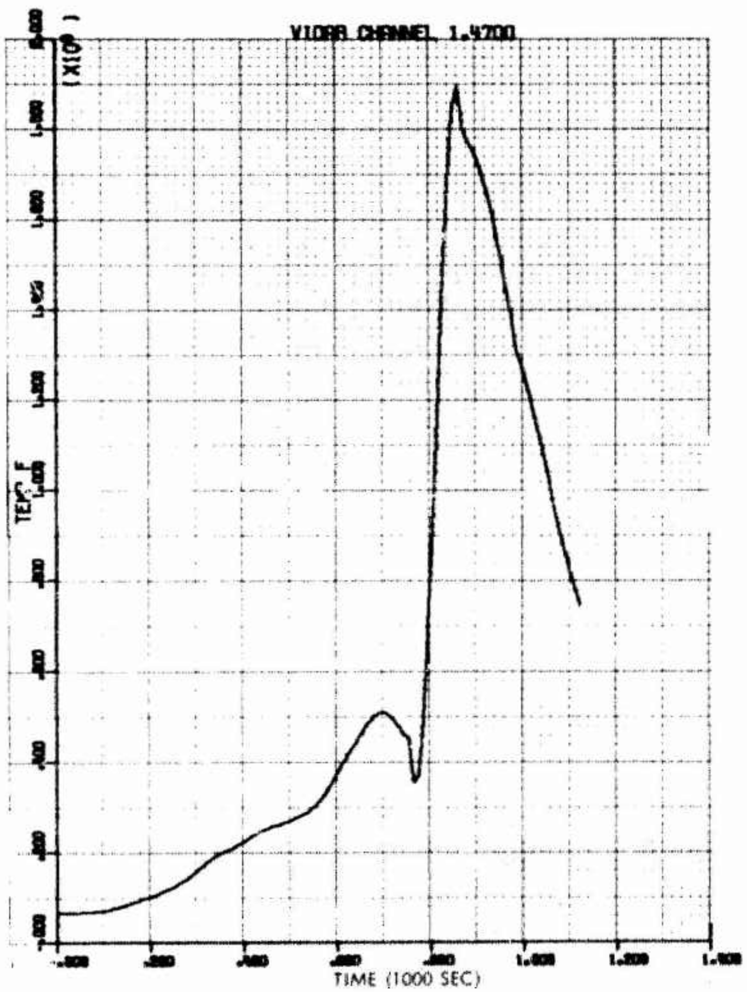


FIG. 83 THERMOGRAM OF FUZE TEST NO. 20 WITH CANDIDATE NO. 14 SLEEVE

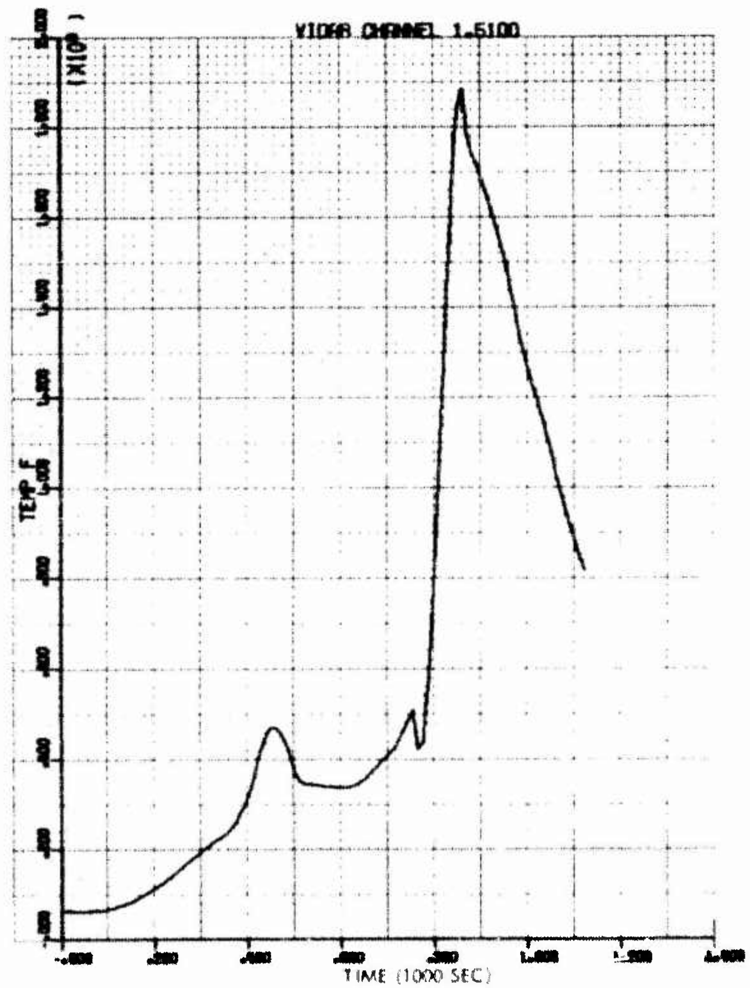


FIG. 84 THERMOGRAM OF FUZE TEST NO. 20 WITH CANDIDATE NO. 10

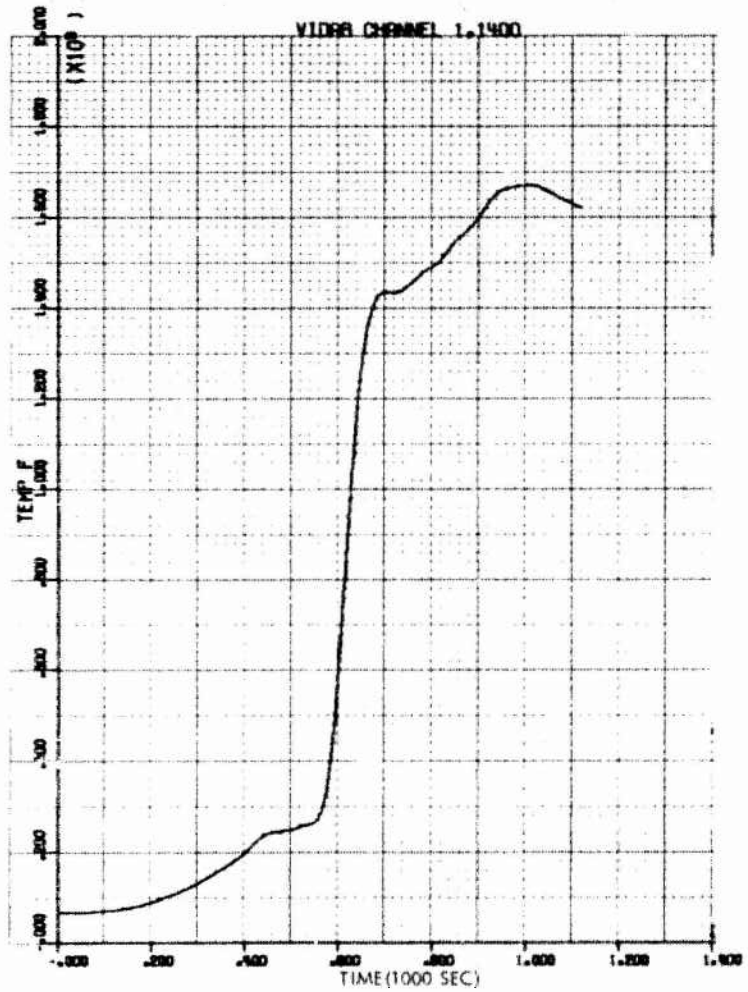


FIG. 85 THERMOGRAM OF ADAPTER BOOSTER THERMOCOUPLE IN FUZE TEST NO. 20 WITH CANDIDATE NO. 5 SLEEVE ON M904E2 FUZE

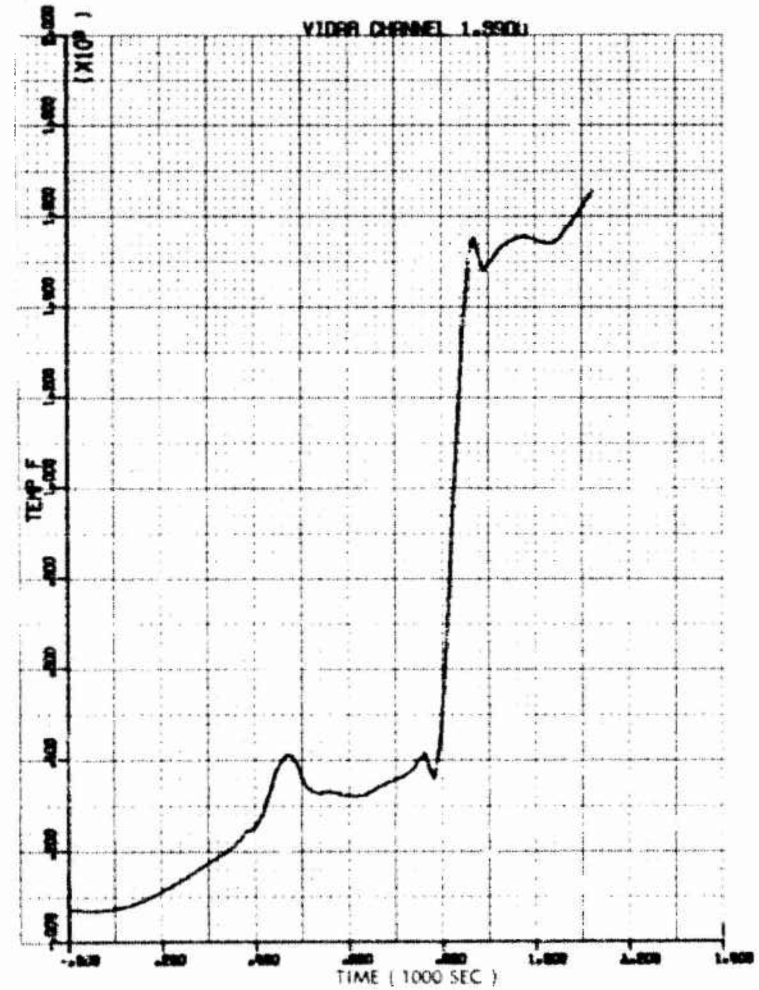


FIG. 86 THERMOGRAM OF ADAPTER BOOSTER THERMOCOUPLE IN FUZE TEST NO. 20 WITH CANDIDATE NO. 14 SLEEVE ON M904E2 FUZE

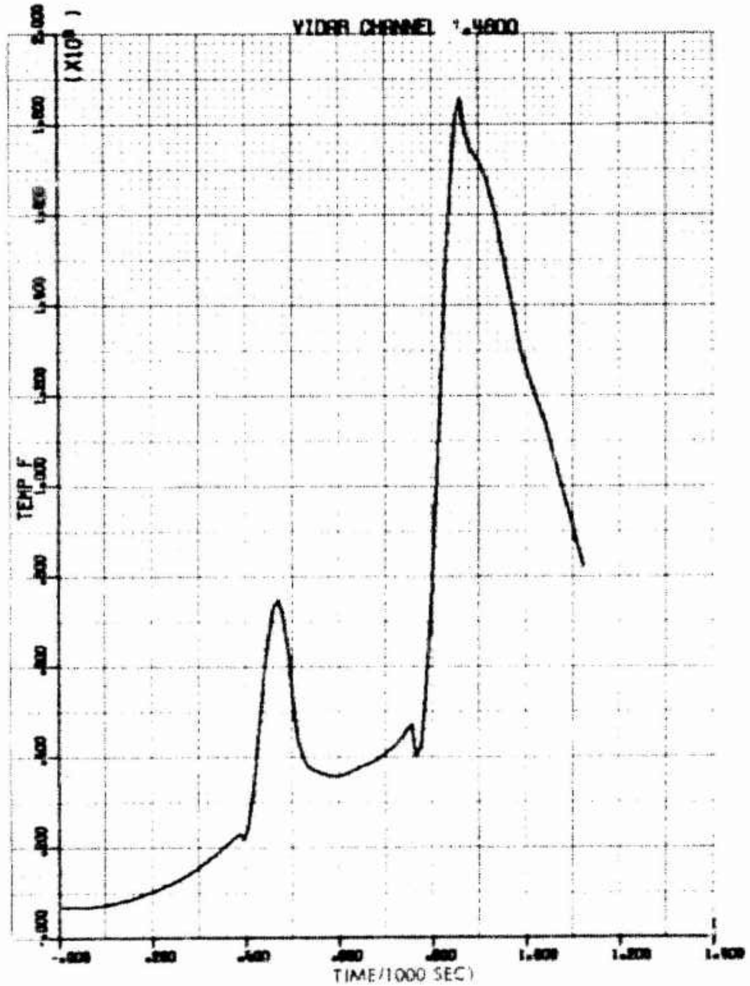


FIG. 87 THERMOGRAM OF ADAPTER BOOSTER THERMOCOUPLE IN FUZE TEST NO. 20 WITH CANDIDATE NO. 1 SLEEVE ON M904E2 FUZE AND WASHER ON ADAPTER

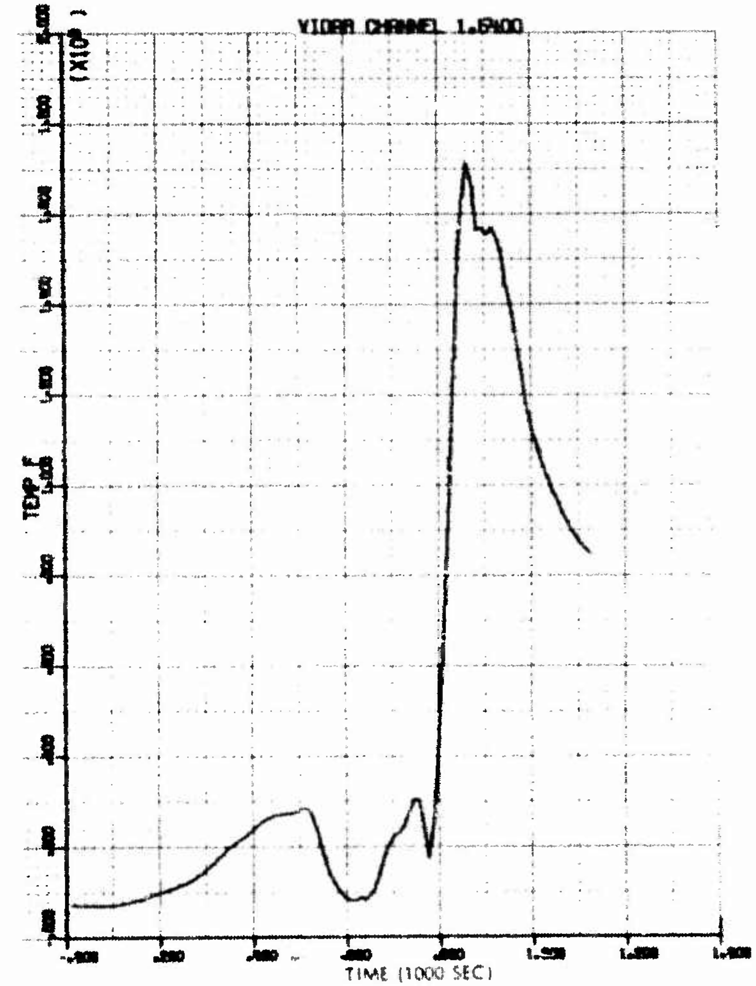


FIG. 88 THERMOGRAM OF ADAPTER BOOSTER THERMOCOUPLE IN FUZE TEST NO. 20 WITH CANDIDATE NO. 10 SLEEVE ON M904E2 FUZE AND WASHER ON ADAPTER BOOSTER RING

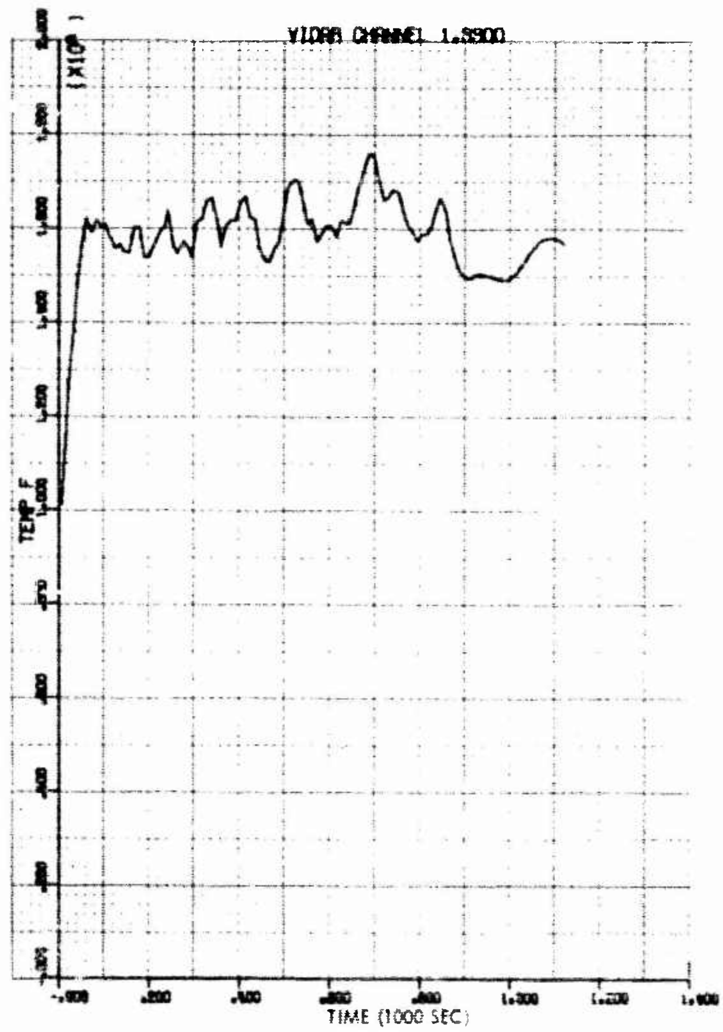


FIG. 89 THERMOGRAM OF FIRE TEMPERATURE THERMOCOUPLE FOR FUZE TEST NO. 20

FIG. 90 TEST SET UP FOR FUZE TEST NO. 20

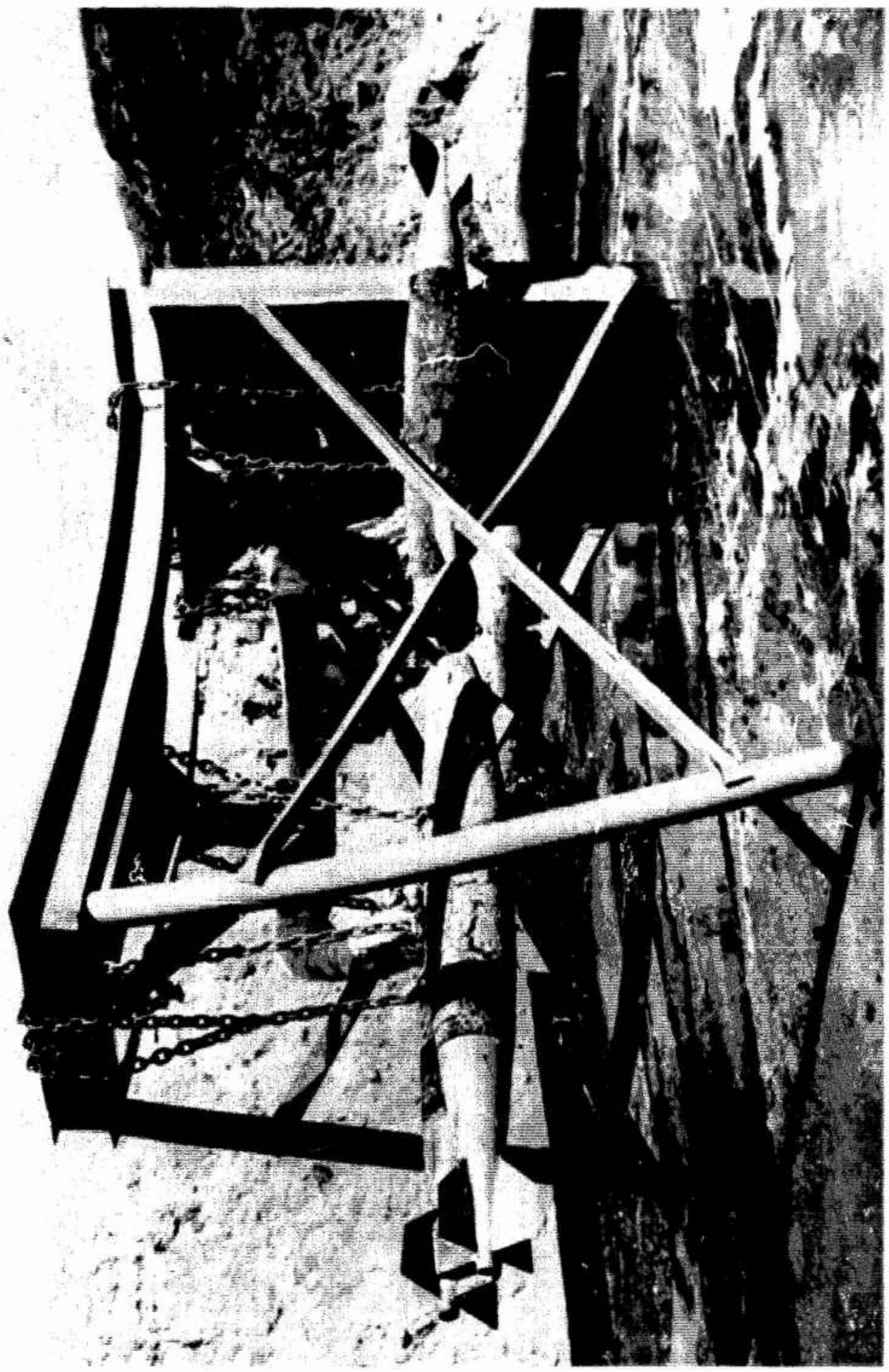


FIG. 91 AFTER THE FIRE - FUZE TEST NO. 20

in twenty minutes fifty-three seconds (1253 seconds). Six and one-half inches of fuel were used in the fire test. The fire burned for 1100 seconds. The fuze with Candidate No. 14 sleeve cooked-off after the fire was going out. Representative thermograms for each of the fuzes and adapter boosters are shown in Figures 92 through 97. Typical fire temperature thermograms are shown in Figure 98. The average fire temperature was 1660°F. Based on the cook-off times obtained in Fuze Tests No. 20 and 21, Candidate No. 5 was eliminated.

Fuze Test No. 22

Fuze Test No. 22 was conducted in order to build the confidence level of the three best fuze fixes tested to date, and to determine the vulnerability of the adapter booster with a fixed fuze.

As before, four inert sand filled thermally protected bombs were tested. One live Fuze M904E2 was protected with a sleeve of Candidate No. 10 material and a washer of Candidate No. 1 material was cemented to the adapter ring. The second live fuze was protected with a Candidate No. 1 sleeve and a Candidate No. 1 washer on the adapter ring. The third live fuze was protected with a Candidate No. 14 sleeve. These fuzes were assembled in inert M148 Adapter Boosters. The fourth fuze was inert and protected with a Candidate No. 14 sleeve and was assembled into a live M148 (T45E7) Adapter Booster.

Eight minutes twenty seconds (500 seconds) after the start of the fire the fuze on the bomb equipped with the Candidate No. 14 sleeve and live M148 Adapter Booster deflagrated.

The fuze with Candidate No. 1 sleeve deflagrated in fourteen minutes thirty seconds (870 seconds). The fuze with Candidate No. 14 deflagrated in sixteen minutes forty seconds (1000 seconds) and the fuze with Candidate No. 10 sleeve deflagrated in twenty minutes thirty-five seconds (1235 seconds). The fire laster 18 minutes and 20 seconds so the fuze with the Candidate No. 10 sleeve reacted after the flame subsided. The reactions were quite mild even after slow cook-off. Figure 99 is a thermogram of the fire temperature. Figures 100-107 are thermograms of thermocouple data. It is interesting to note again that even after the fire is out the explosive continues to self heat until the ignition point is reached.

The data on this section of the fuze program is summarized in Table 20.

As a result of the preceding tests, the choice for a protective covering was narrowed from a field of fifteen candidates to three. The most promising were (1) Candidate No. 1, (2) Candidate No. 14 and (3) Candidate No. 10.

The following fire tests were designed to uncover any deficiencies in the insulative properties of the sleeve, and to

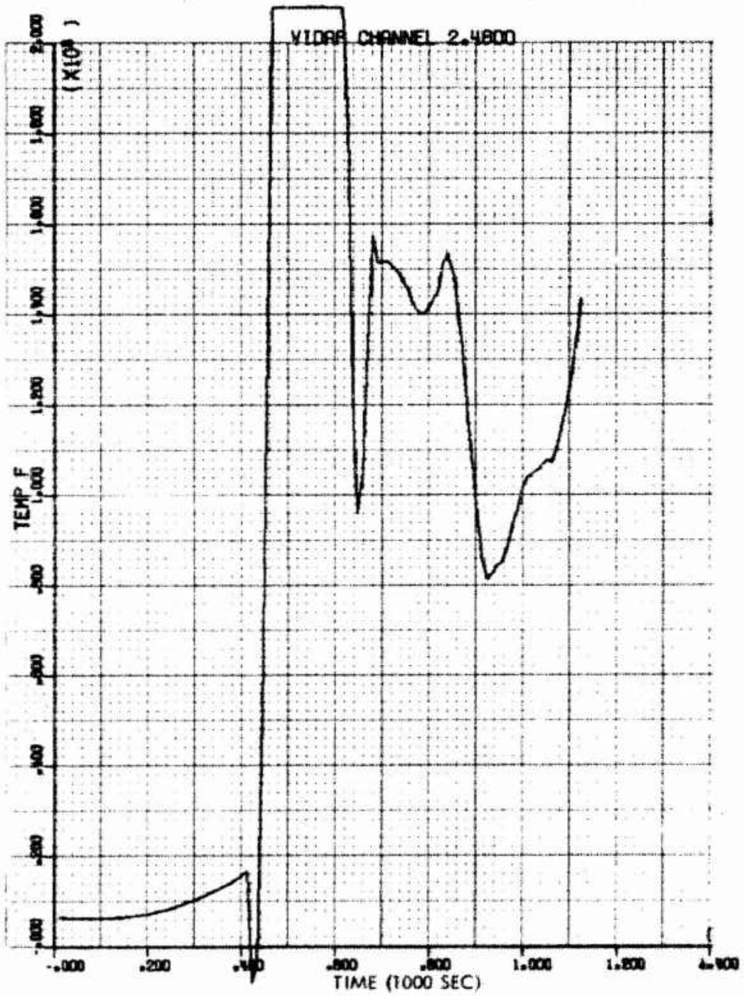


FIG. 92 FUZE TEST NO. 21 - THERMOGRAM OF M904E2 FUZE PROTECTED WITH CANDIDATE NO. 5 SLEEVE

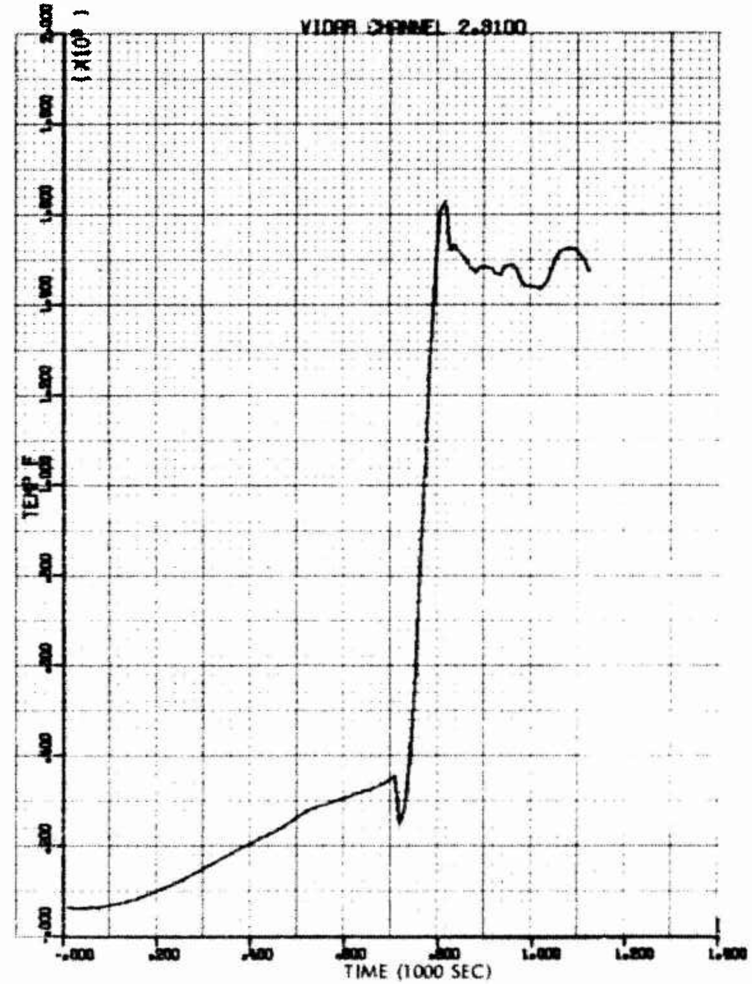


FIG. 93 FUZE TEST NO. 21 - THERMOGRAM OF M904E2 FUZE PROTECTED WITH CANDIDATE NO.1 SLEEVE

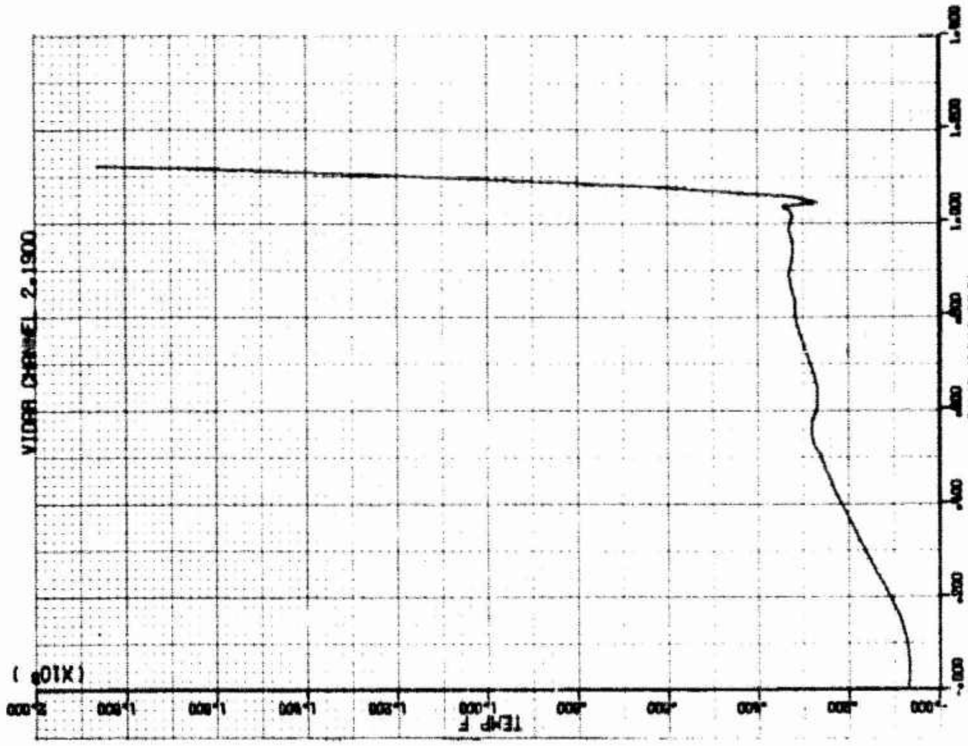


FIG. 95 FUZE TEST NO. 21 THERMOGRAM OF FUZE PROTECTED WITH CANDIDATE NO. 10 SLEEVE

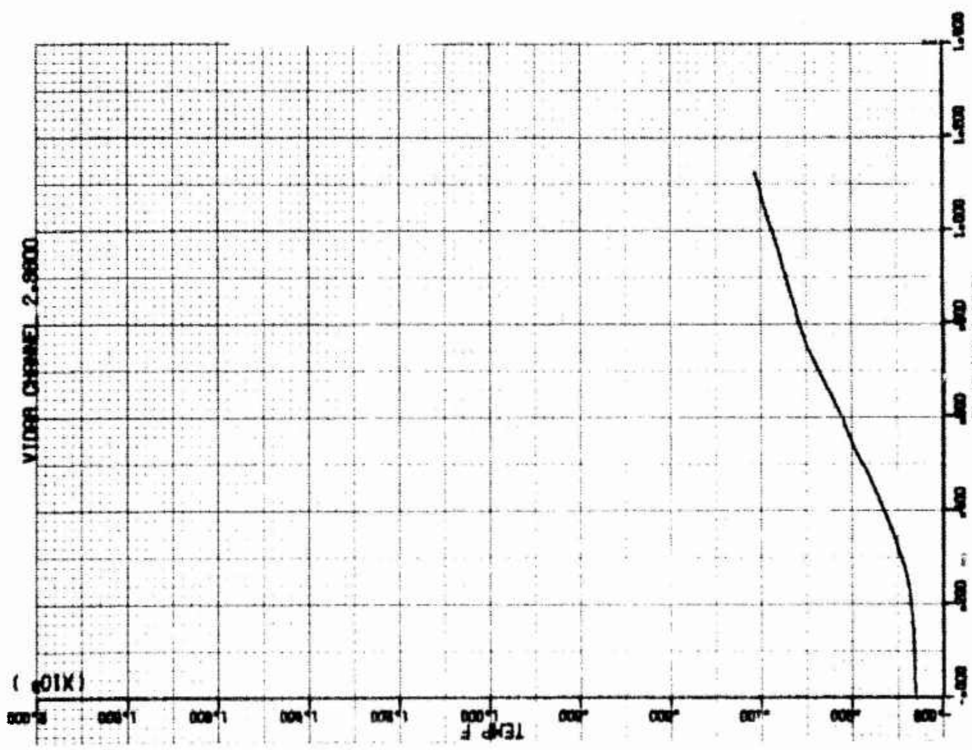


FIG. 94 FUZE TEST NO. 21 - THERMOGRAM OF FUZE PROTECTED WITH THE CANDIDATE NO. 14 SLEEVE

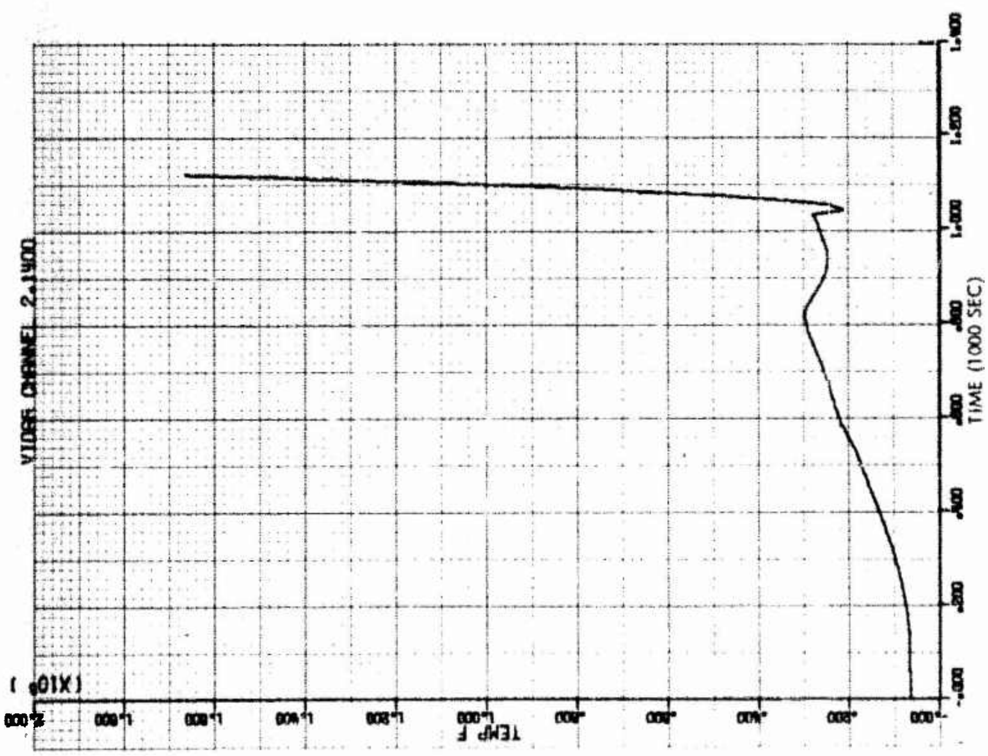


FIG. 96 FUZE TEST NO. 21 THERMOGRAM ON INERT M148 ADAPTER BOOSTER THERMOCOUPLE WITH LIVE M904E2 FUZE PROTECTED WITH CANDIDATE NO. 10 SLEEVE AND WASHER

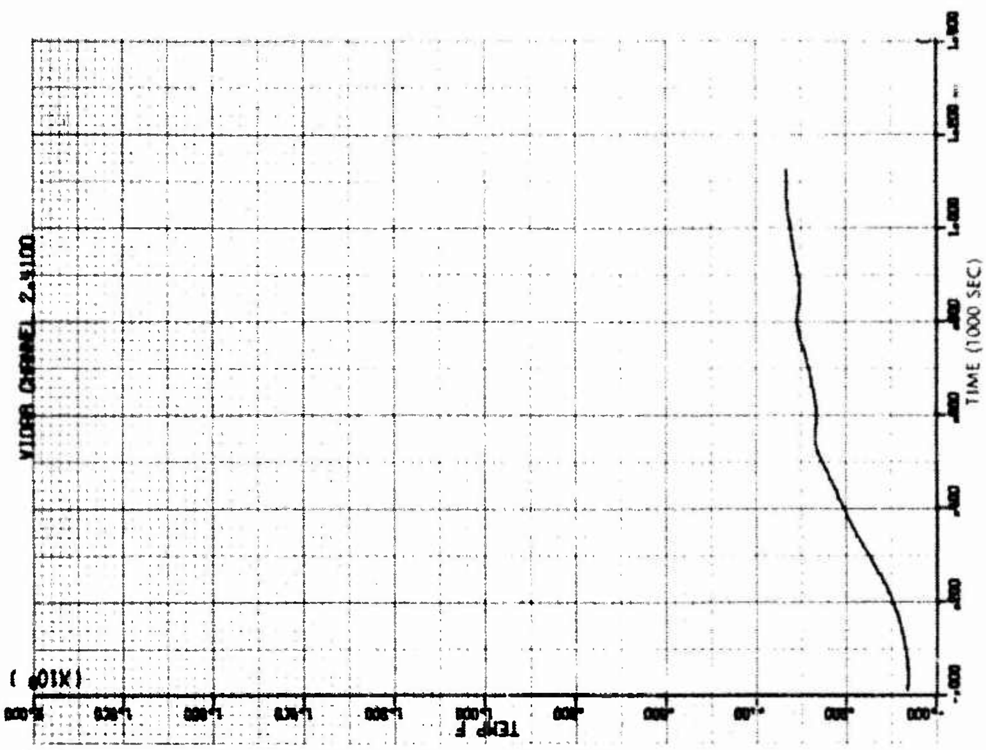


FIG. 97 FUZE TEST NO. 21 THERMOGRAM OF INERT M148 ADAPTER BOOSTER THERMOCOUPLE WITH LIVE FUZE M904E2 PROTECTED WITH A CANDIDATE NO. 14 SLEEVE

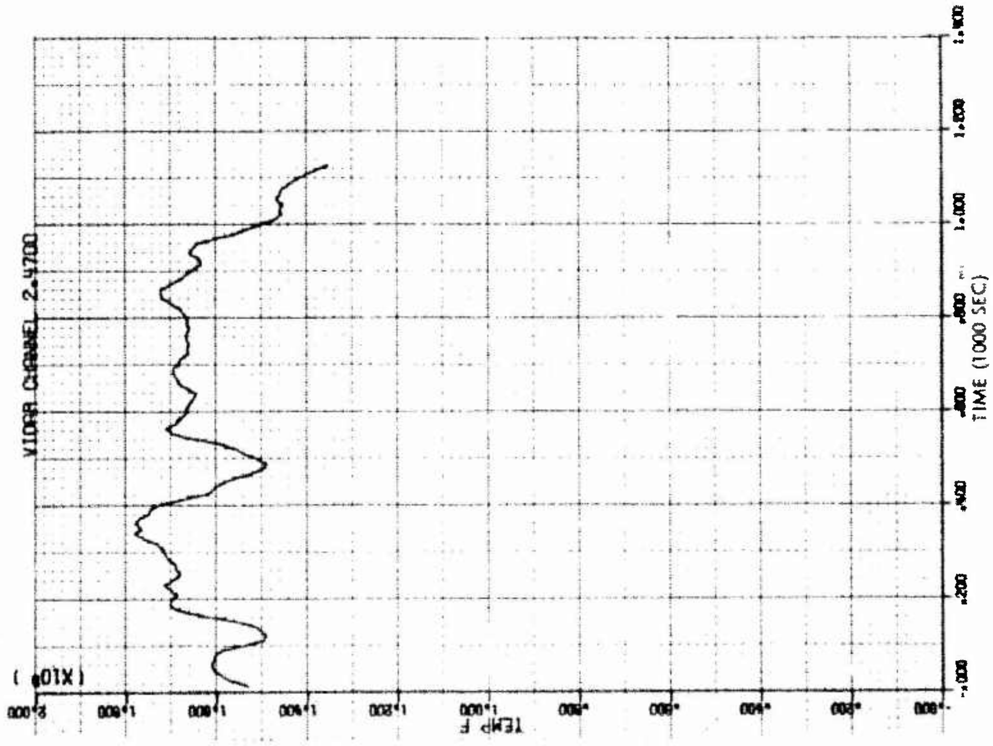


FIG. 98 FUZE TEST NO. 21 THERMOGRAM OF FIRE TEMPERATURE THERMOCOUPLE

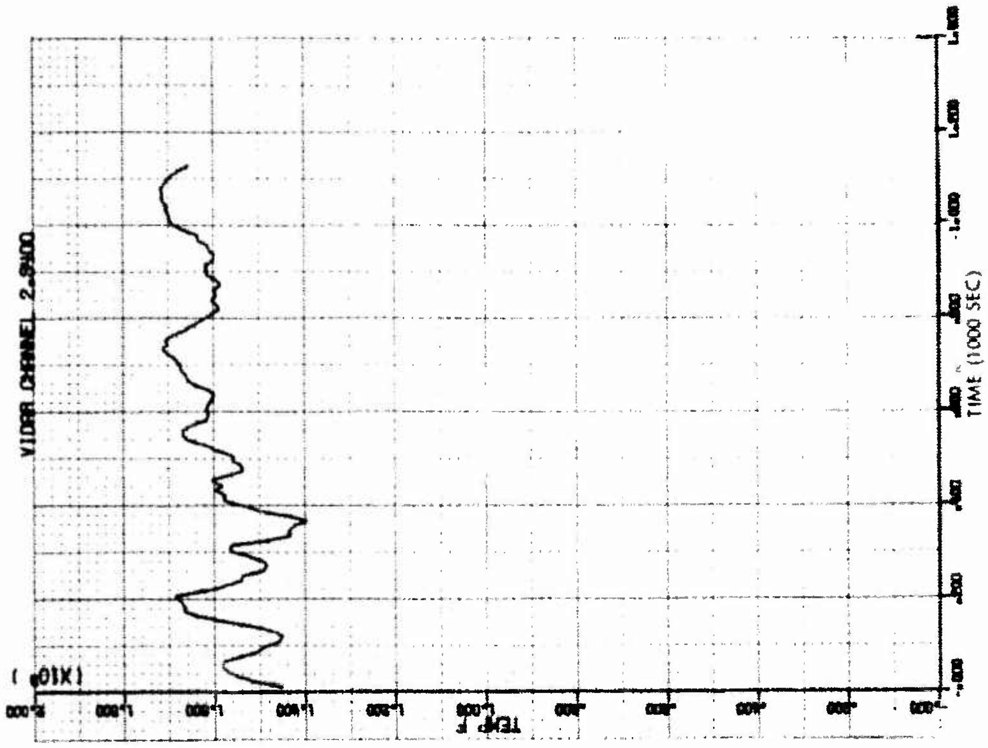


FIG. 99 FUZE TEST NO. 22 THERMOGRAM OF FIRE TEMPERATURE THERMOCOUPLE

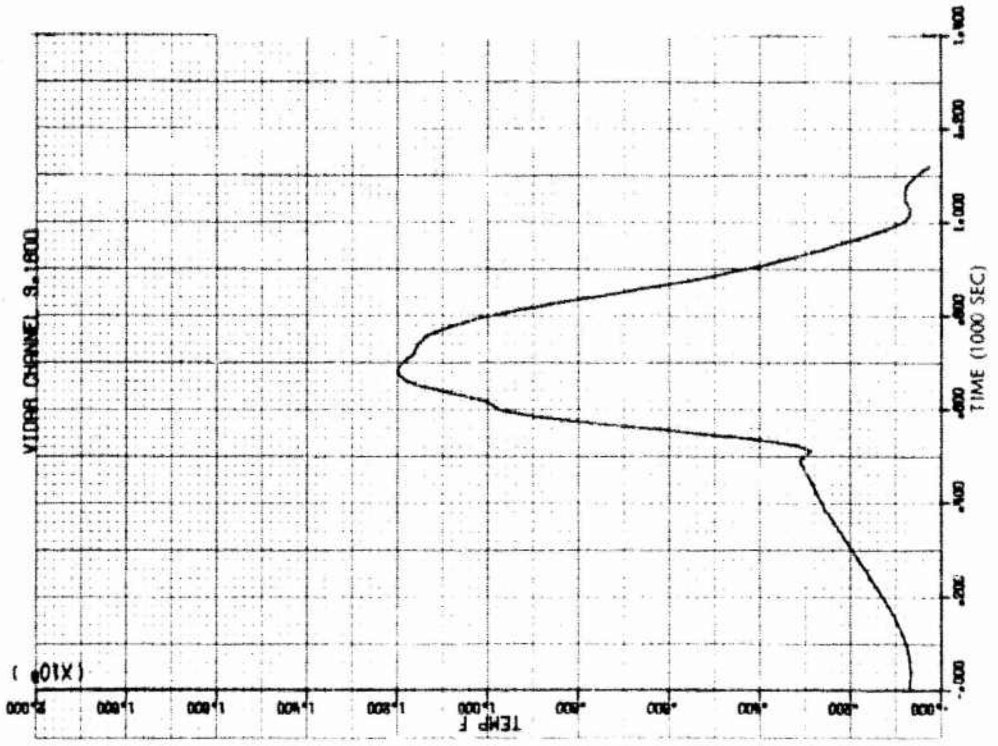


FIG. 100 FUZE TEST NO. 22 THERMOGRAM OF INERT M904E2 FUZE PROTECTED WITH CANDIDATE NO.14 SLEEVE

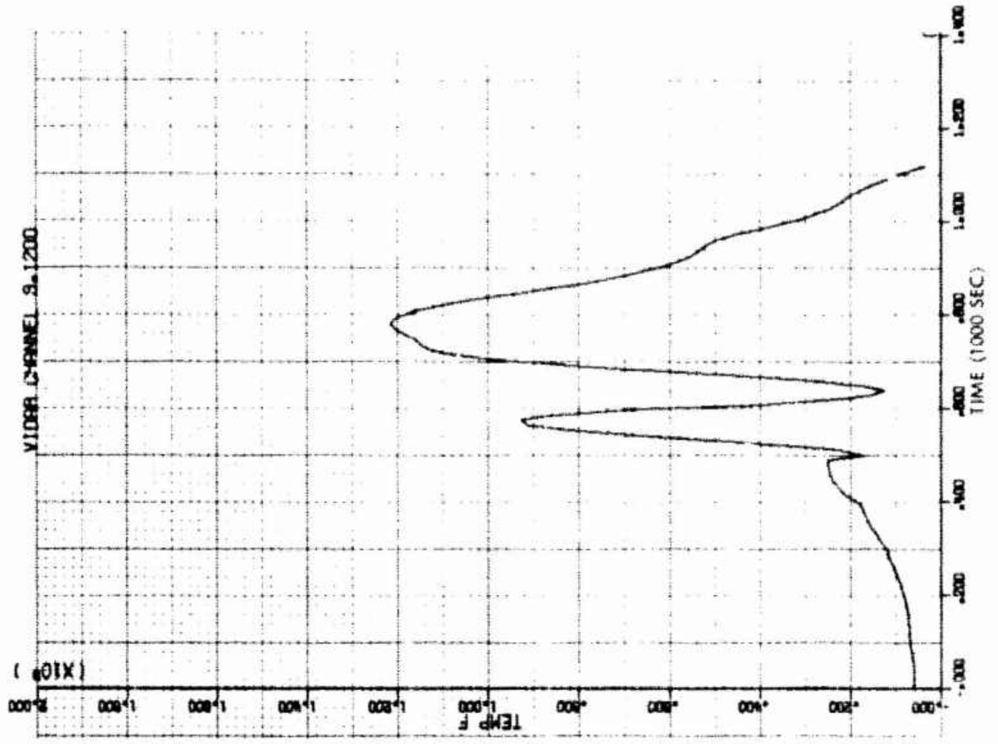


FIG. 101 FUZE TEST NO. 22 THEROGRAM OF LIVE M148 ADAPTER BOOSTER - INERT M904E2 FUZE PROTECTED WITH THE CANDIDATE NO. 14 SLEEVE

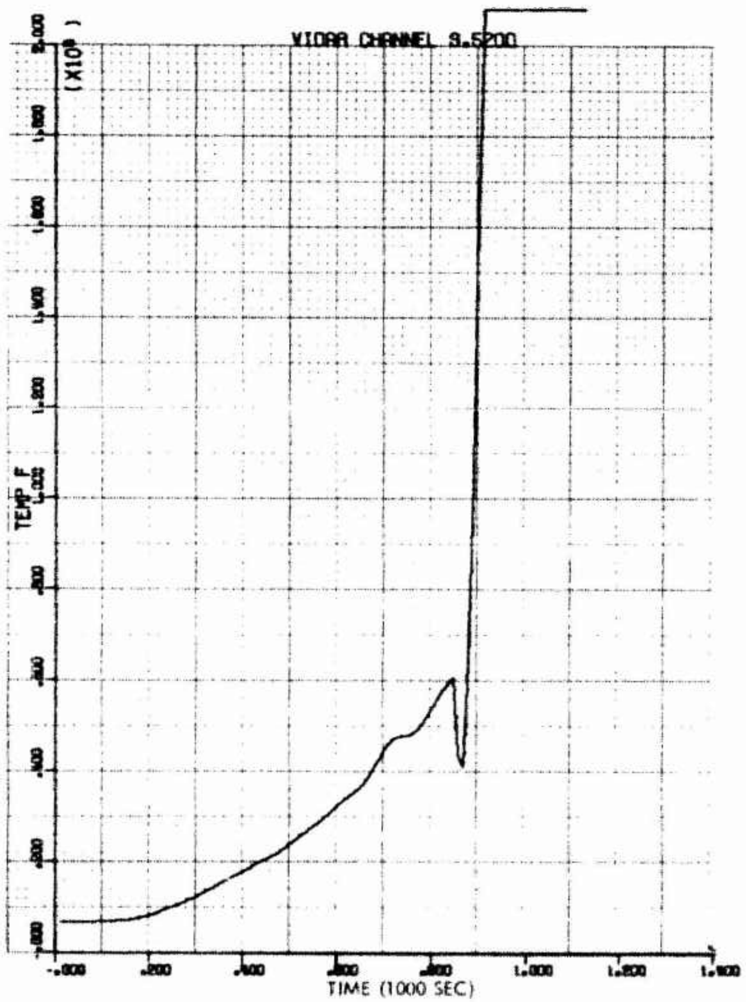


FIG. 102 FUZE TEST NO. 22 THERMOGRAM OF LIVE M904E2 FUZE PROTECTED WITH A CANDIDATE NO. 1 SLEEVE

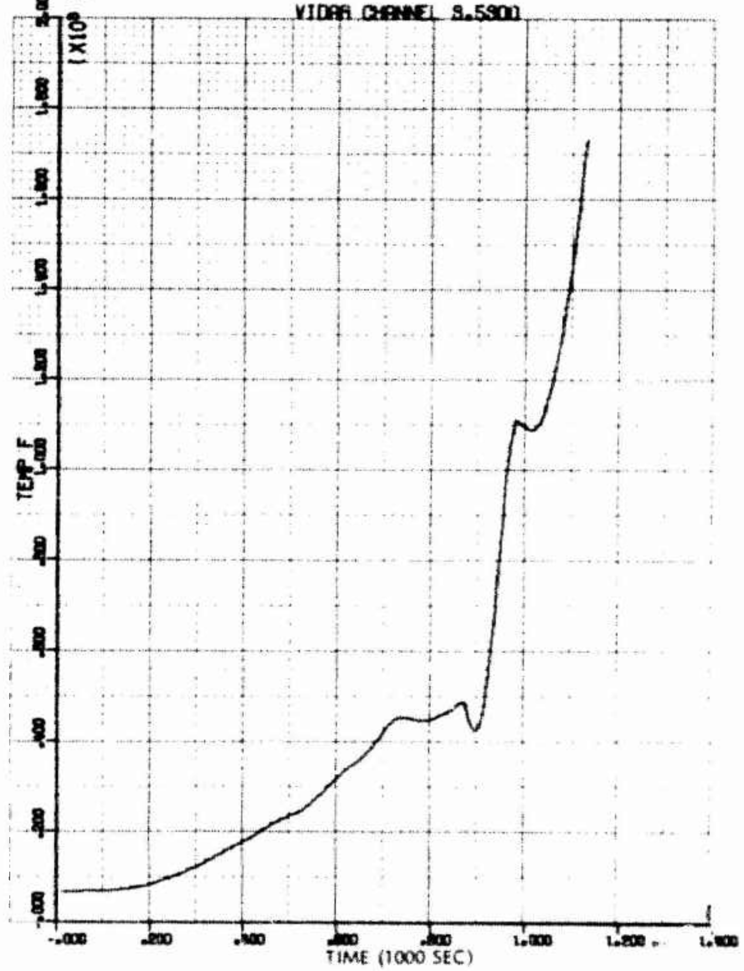


FIG. 103 FUZE TEST NO. 22 THERMOGRAM OF INERT M148 ADAPTER BOOSTER WITH CANDIDATE NO. 1 SLEEVE

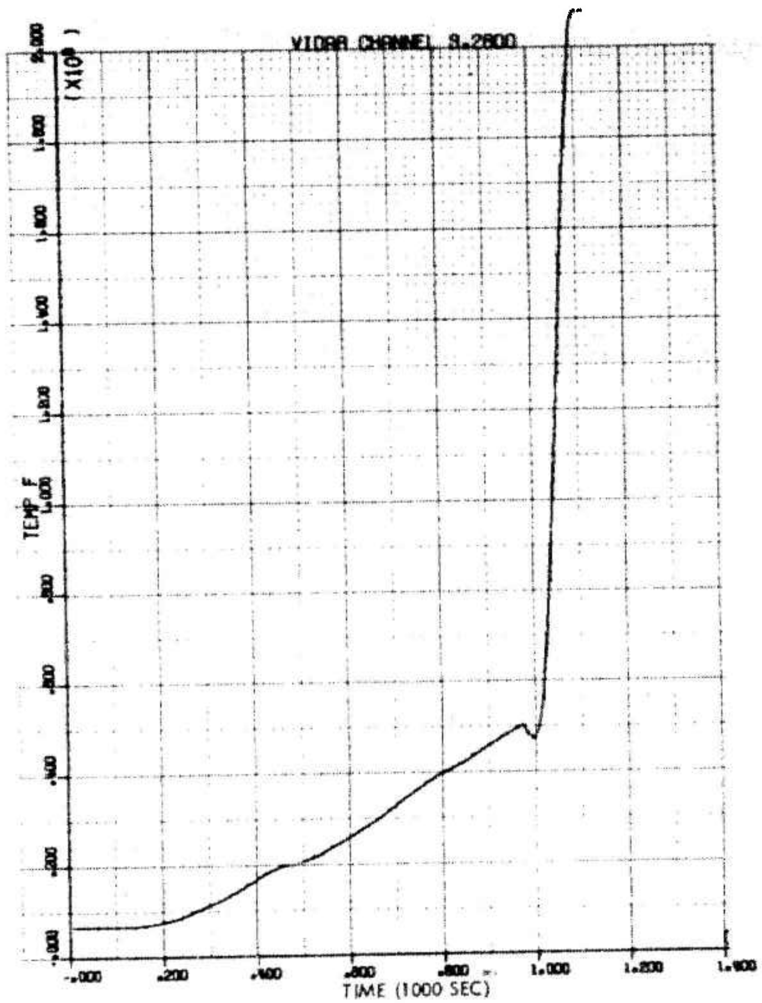


FIG. 104 FUZE TEST NO. 22 THERMOGRAM OF LIVE M904E2 FUZE PROTECTED WITH CANDIDATE NO. 14 SLEEVE

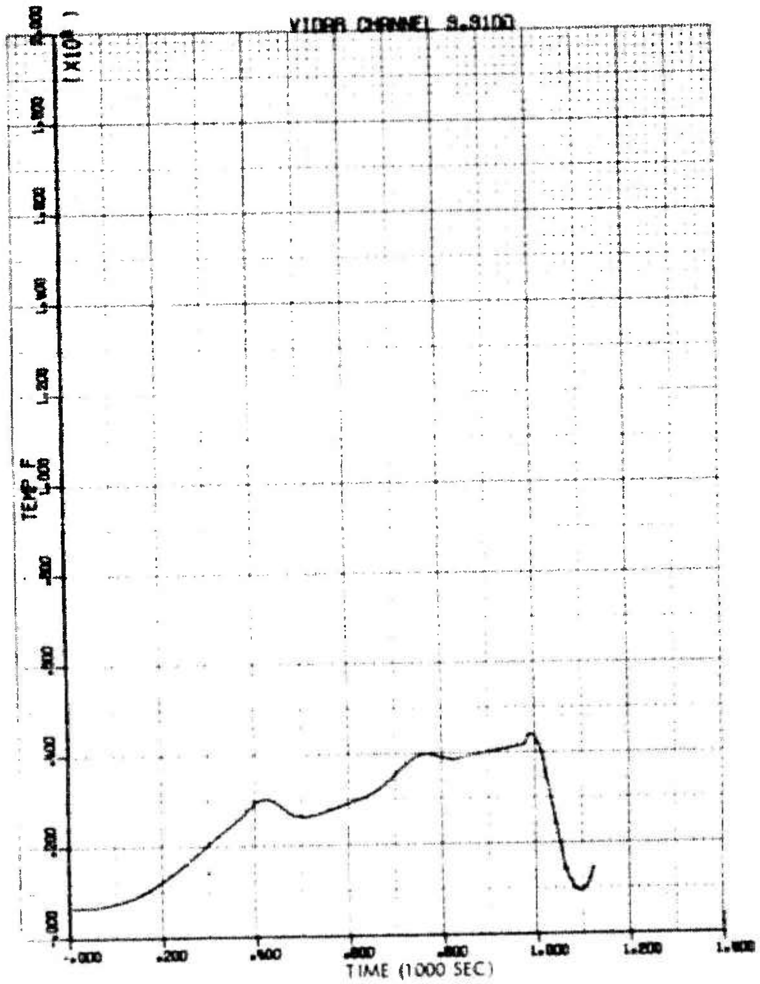


FIG. 105 FUZE TEST NO. 22 THERMOGRAM OF INERT M148 ADAPTER BOOSTER - WITH LIVE M904E2 FUZE PROTECTED WITH CANDIDATE NO. 14 SLEEVE

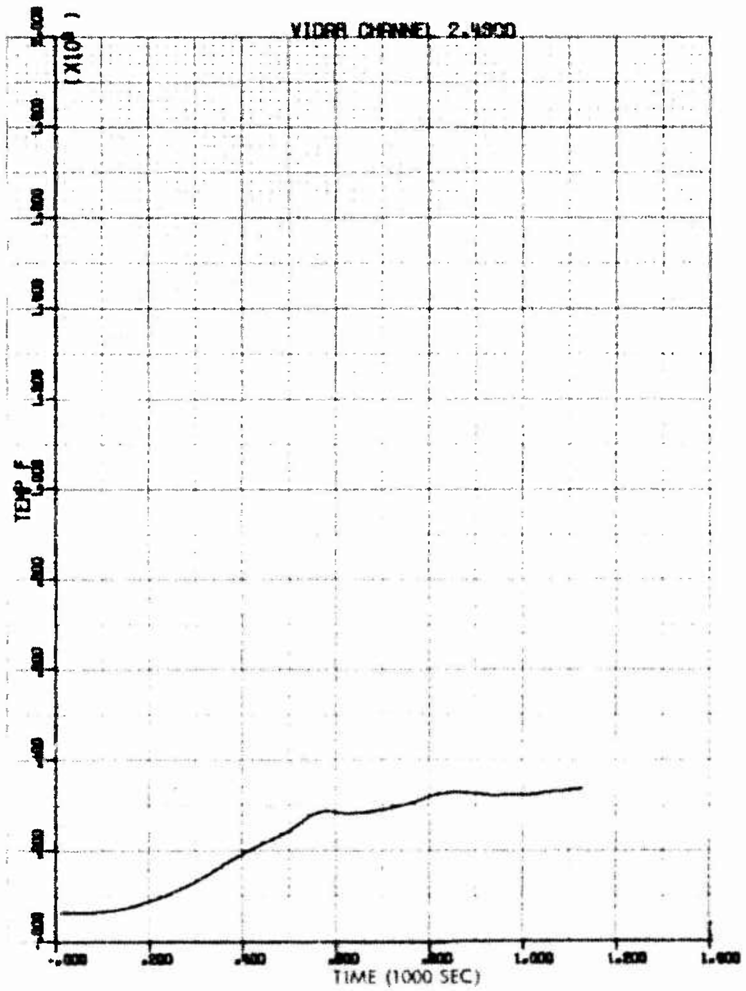


FIG. 106 FUZE TEST NO. 22 THERMOGRAM OF A LIVE M904E2 FUZE PROTECTED WITH CANDIDATE NO.10 SLEEVE

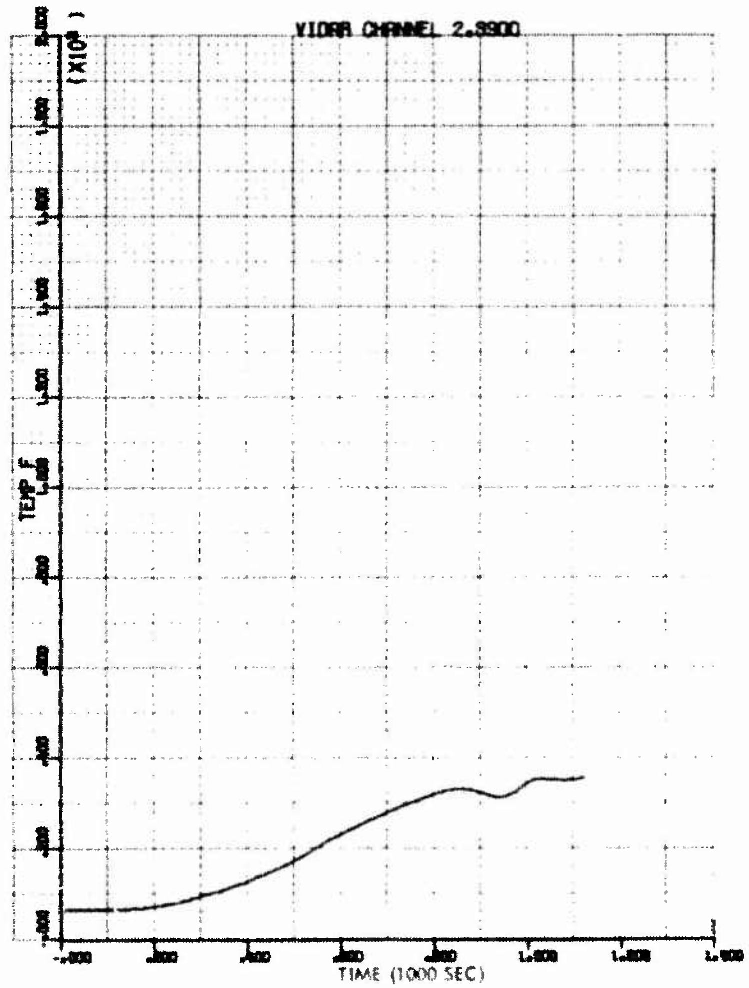


FIG. 107 FUZE TEST NO. 22 THERMOGRAM OF AN INERT M148 ADAPTER BOOSTER WITH LIVE M904E2 FUZE PROTECTED WITH CANDIDATE NO. 10 SLEEVE

Table 20

Cook-Off Results on Nose Fuze M904E2 Equipped with Various Protective Coverings Bonded with RTV 737

Fuze Test No.	Mk 82 Bomb Configuration	Nose Fuze M904E2 Configuration	Adapter Booster Configuration	Reaction Time Sec.	Kind of Reaction
17	Inert-sand filled with ¼" High Melting Hot Melt	Live with ¼" Candidate No. 14 Sleeve	Inert-sand filled.	360*	Deflagration
17	Same as above	Live with ¼" Candidate No. 8 Sleeve	Same as above	480*	Deflagration
17	Same as above	Live with ¼" Candidate No. 1 Sleeve	Same as above	540*	Deflagration
18	Inert-sand filled with ¼" High Melting Hot Melt and Intumescent Paint on Adapter Ring and on Bomb	Live with ¼" Candidate No. 12 Sleeve	Inert-sand filled.	540	Deflagration
18	Same as above	Live with Candidate No. 4	Same as above	756	Deflagration
18	Same as above	Live with Candidate No. 7	Same as above	948	Deflagration
19	Same as above	Live with ¼" Candidate No. 14 Sleeve	Same as above	530	Deflagration
19	Same as above	Live with ¼" Candidate No. 1 Sleeve	Same as above	598	Deflagration
19	Same as above	Live with ¼" Candidate No. 8 Sleeve	Same as above	538	Deflagration

Table 20 (Con't.)

Fuze Test No.	Mk 82 Bomb Configuration	Nose Fuze M904E2 Configuration	Adapter Booster Configuration	Reaction Time Sec.	Kind of Reaction
20	Thermally protected bomb. No paint on adapter ring.	Live with Candidate No. 5 covering front of bomb.	Inert-sand filled	560	Deflagration
20	Same as above	Live with Candidate No. 1 sleeve extended 1" with grooves cut in end to fit over front of bomb.	Same as above	760	Deflagration
20	Same as above	Live with Candidate No. 10 $\frac{1}{4}$" sleeve and Candidate No. 1 disc on adapter ring.	Same as above	760	Deflagration
20	Same as above	Live with Candidate No. 14 sleeve to conform to shape of bomb.	Same as above	780	Deflagration
21	Same as above	Live with Candidate No. 5 covering front of bomb.	Same as above	440	Deflagration
21	Same as above	Live with Candidate No. 1 washer on adapter ring.	Same as above	720	Deflagration
21	Same as above	Live with Candidate No. 10 & Candidate No. 1 disc on adapter booster.	Same as above	1040	Deflagration
21	Same as above	Live with Candidate No. 14 sleeve made to conform to shape of bomb.	Same as above	1100	Deflagration

Table 20 (Con't.)

Fuze Test No.	Mk 82 Bomb Configuration	Nose Fuze M904E2 Configuration	Adapter Booster Configuration	Reaction Time Sec.	Kind of Reaction
22	Thermally protected bomb. No paint on adapter ring.	Live with Candidate No. 1 sleeve and washer of Candidate No. 1.	Inert-sand filled	870	Deflagration
22	Same as above	Live with Candidate No. 10 sleeve and washer of Candidate No. 1.	Same as above	1235**	Deflagration
22	Same as above	Live with Candidate No. 14 sleeve to conform to shape of bomb.	Same as above	1000	Deflagration
22	Same as above	Inert with Candidate No 14 sleeve made to conform to shape of bomb.	Live T45E7	500	Deflagration

* Thermocouples shorted out because of improper insulation. Times to cook-off obtained from reaction sounds.

** Fire lasted 1100 seconds.

build up the confidence level of the fixes. Ultimately, one material would be chosen as a back-up in case any deficiencies were uncovered in the evaluation phase of the program.

Concrete loaded Mk 82 Bombs were used in this phase of the program. These bombs were readily available, and served as a reasonably good simulant for the explosive. The bombs were painted on the exterior with intumescent paint and are referred to as thermally protected bombs.

Fuze Test No. 23

In previous discussions, both a washer and intumescent paint were used on the exterior of the adapter ring. Fuze Test No. 23 was accomplished to select the paint or the washer as an adapter ring fix. The paint was shown to be effective previously in the open adapter booster fixes.

Four thermally protected Mk 82 Bombs were used as in our previous tests. Two of the bombs contained live Fuzes M904E2 and inert M148 Adapter Boosters and two contained inert Fuzes M904E2 and live M148 Adapter Boosters. All of the fuzes were protected with Candidate No. 1 sleeves. One of the live M148 Adapter Boosters contained a washer cemented to the adapter ring with RTV 737. The other was coated with intumescent paint. The inert adapter booster rings were equipped in a similar fashion.

The instrumentation of the fuzes both live and inert was similar to those in previous tests. Four thermocouples were placed symmetrically around the fuze in the same horizontal plane at the center of the delay element. The adapter boosters were instrumented by placing four thermocouples in contact with tetryl in the adapter booster. This is shown in Figure 108. Eight thermocouples were placed in the flame to record the fire temperature. Nine minutes fifty seconds (590 seconds) after ignition of the fuel, the bomb with the live Nose Fuze M904E2, Candidate No. 1 sleeve and Insunol paint on the adapter ring deflagrated. The reaction was minor. The thermocouple data for the Fuze M904E2 and M148 Adapter Booster are shown in Figures 109 and 110. The second reaction occurred at ten minutes twenty-five seconds (625 seconds) after the start of the fire. The bomb contained an inert Nose Fuze M904E2, Candidate No. 1 sleeve and a washer of Candidate No. 1 material cemented to the face of the adapter ring. The reaction was a detonation. The nose of the bomb was peeled back. This is shown in Figure 111. The thermocouple data for the fuze and adapter booster is shown in Figures 112 and 113.

The third bomb contained an inert Nose Fuze M904E2, Candidate No. 1 sleeve and a live M148 Adapter Booster with the adapter ring coated with Insunol intumescent paint. A deflagration occurred eleven minutes fifty seconds (710 seconds) after the start of the fire. The reaction was mild. Figure 114 is a typical thermogram

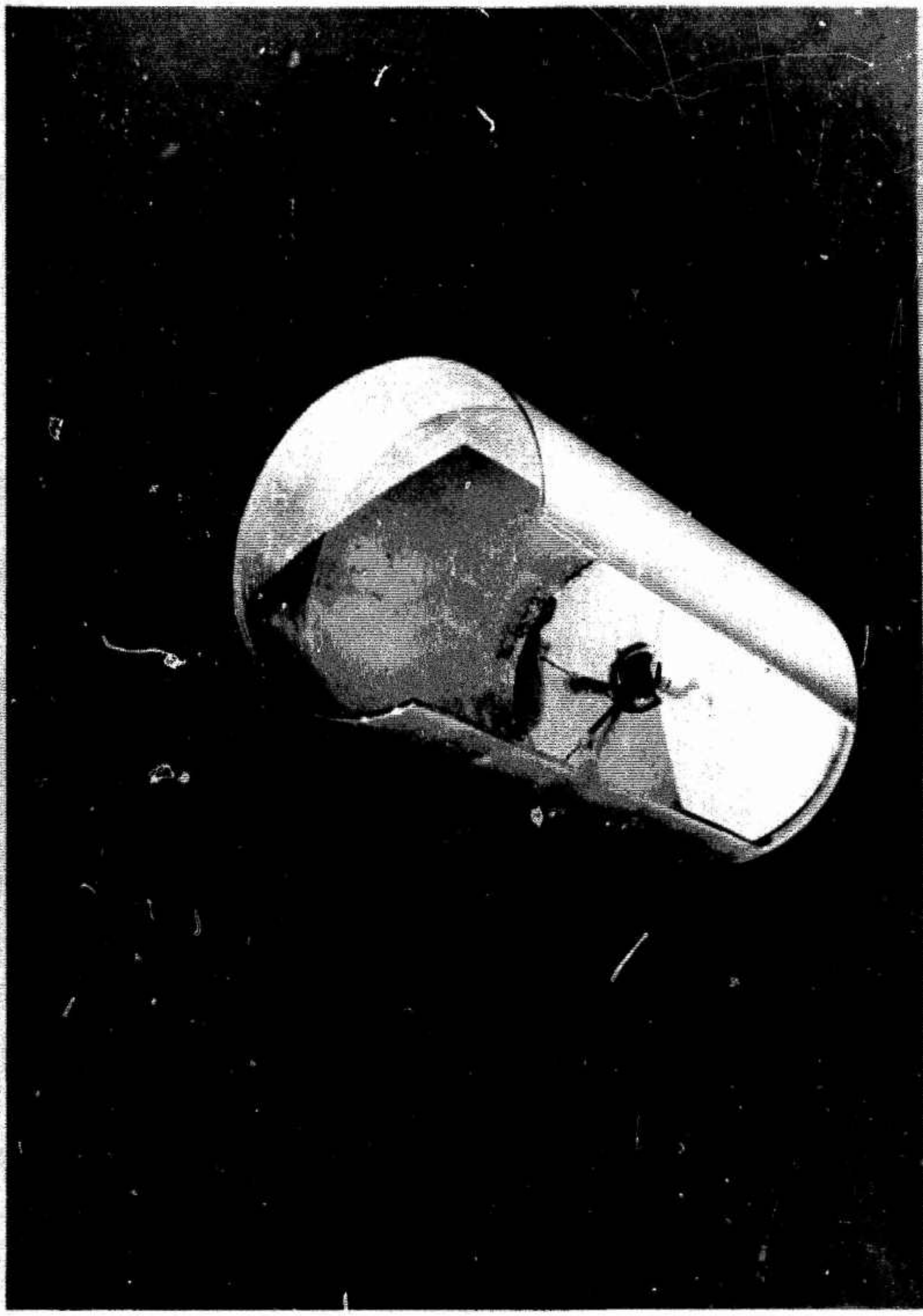


FIG. 108 EXPOSED VIEW OF THERMOCOUPLES INSTALLED IN AN ADAPTER BOOSTER

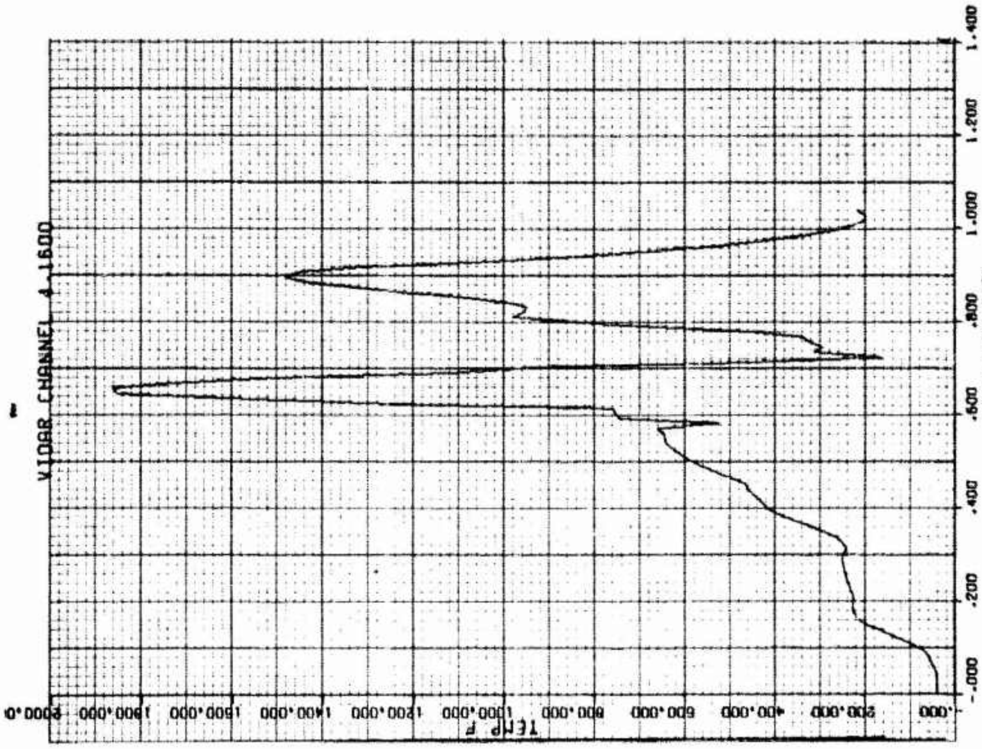


FIG. 109 FUZE TEST NO. 23-THERMOGRAM OF A LIVE M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

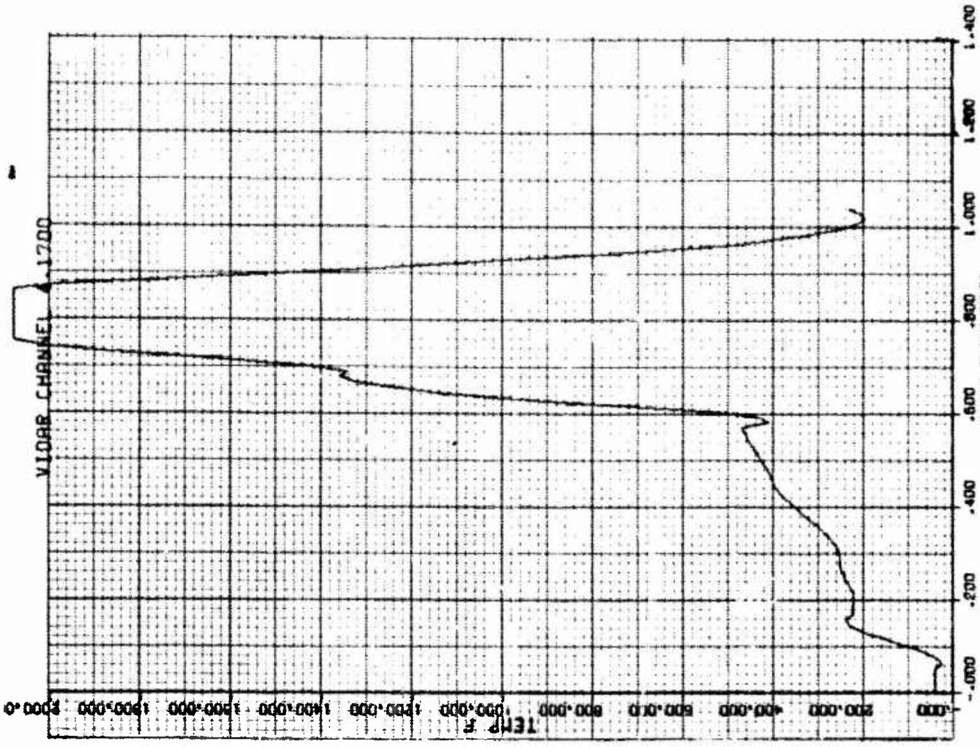


FIG. 110 FUZE TEST NO. 23-THERMOGRAM OF AN INERT M148 ADAPTER BOOSTER CONTAINING A M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

FIG. 111 FUZE TEST NO. 23 PHOTOGRAPH OF MK 82 BOMB AFTER COOK-OFF TEST

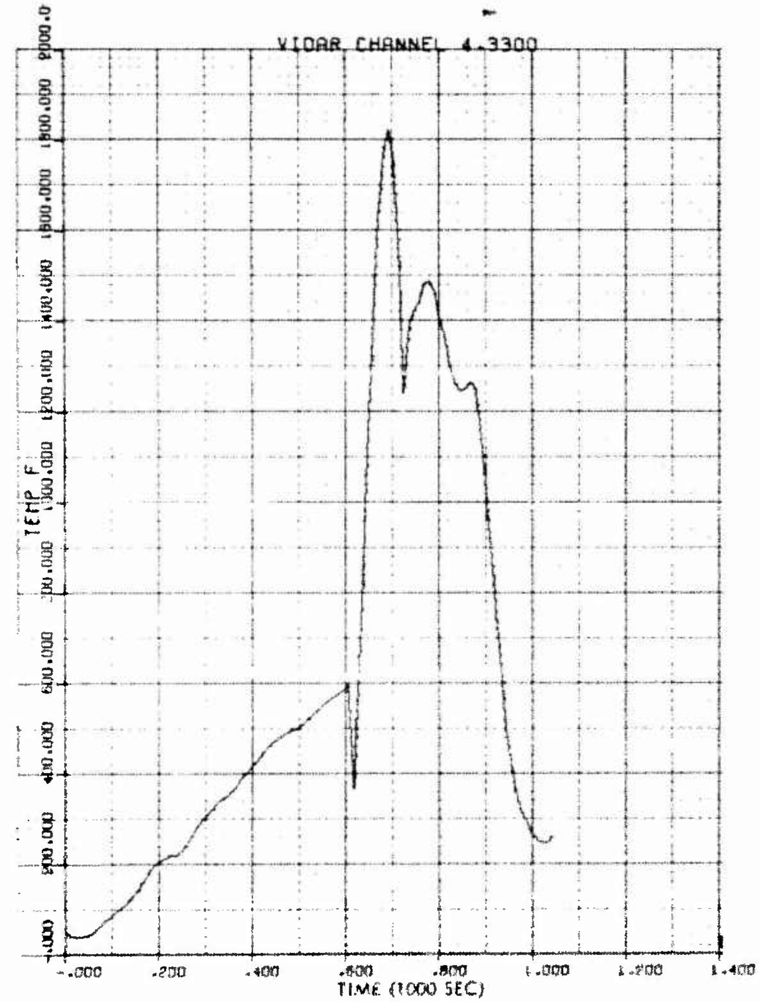


FIG. 112 FUZE TEST NO. 23-THERMOGRAM OF AN INERT M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

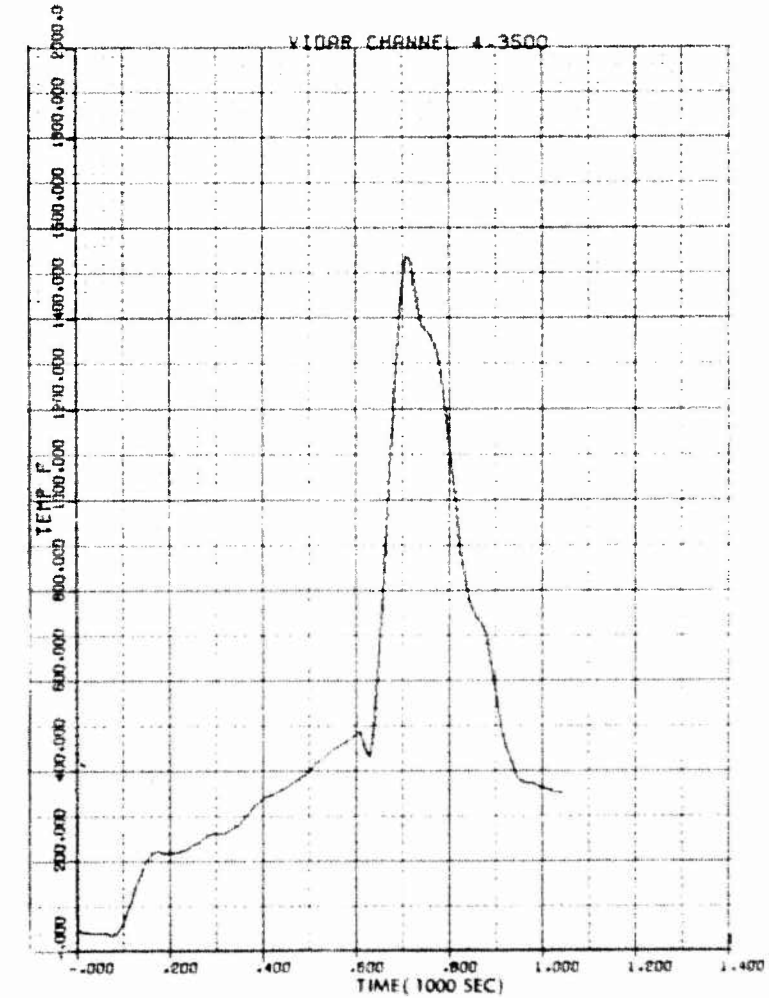


FIG. 113 FUZE TEST NO. 23 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING A FUZE M904E2 PROTECTED WITH CANDIDATE NO. 1 SLEEVE

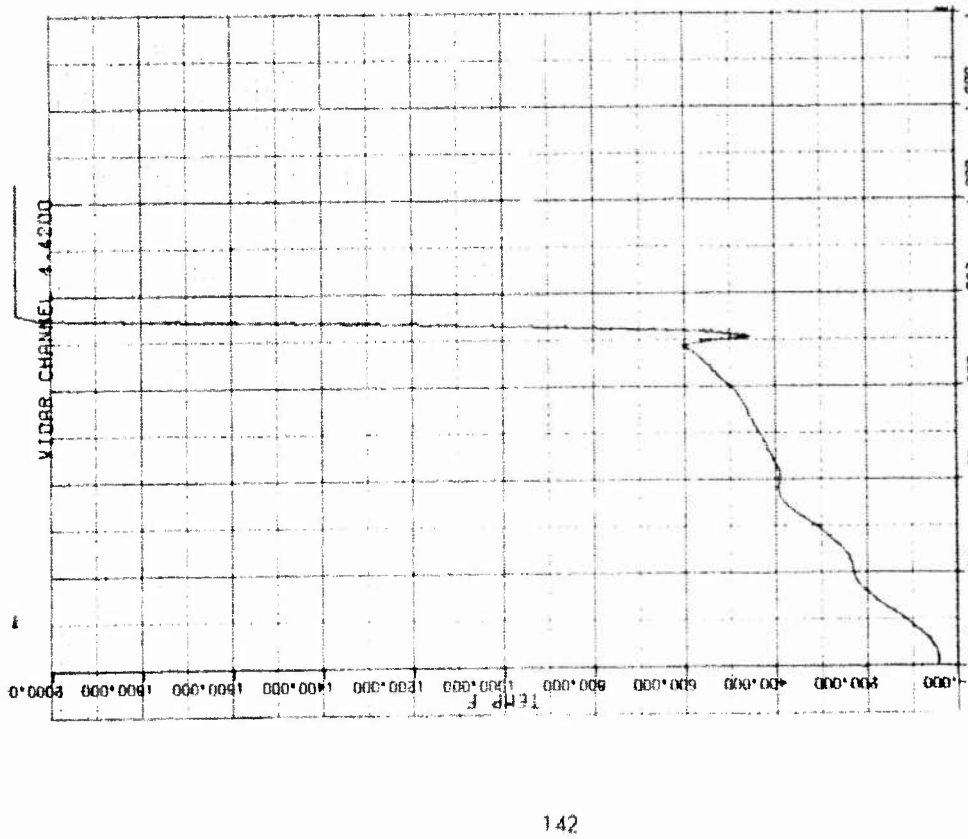


FIG. 114 FUZE TEST NO. 23 THERMOGRAM OF AN INERT M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

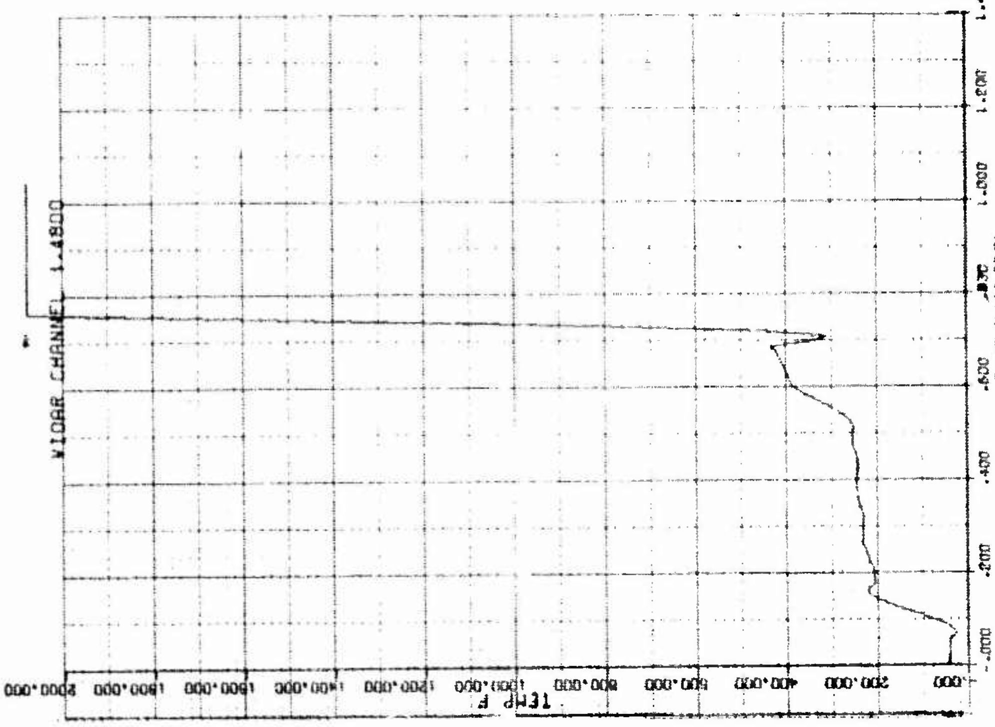


FIG. 115 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

of a thermocouple in the inert Fuze M904E2. Figure 115 indicates the cook-off temperature and time of the live adapter booster. The plateau on the adapter booster thermogram may indicate when intumescence is occurring; however, it does not indicate the intumescent temperature because of heat loss along the adapter booster.

The fourth bomb contained a live Nose Fuze M904E2 with Candidate No. 1 sleeve. A washer of Candidate No. 1 material was cemented to the face of the adapter ring of the inert M148 Adapter Booster. Cook-off occurred in thirteen minutes thirty seconds (810 seconds). The reaction was a deflagration. The time temperature plot of the fuze is shown in Figure 116. The time temperature plot of the adapter booster is shown in Figure 117. Here we notice the plateau is gone.

The thermal protection of the paint and washer were similar and were within the experimental error of this measurement. From an operation viewpoint, the washer would be in the way in assembly of the adapter booster into the bomb and difficult to completely bond to the adapter ring. For these reasons the washer was judged to be impractical. As a result of this test, the washer was discarded in favor of the intumescent paint. In all M148 Adapter Boosters for future tests the adapter ring face was coated with the Insunol system (intumescent paint and barrier coat).

The formulation of the Insunol system and the source of material are noted on NAVAIR Dwg. No. 599AS105 included as Appendix D.

Fuze Test No. 24

Fuze Test No. 24 was conducted to evaluate the reliability of the other two fuze coverings. Two inert Nose Fuzes M904E2 were prepared, one with Candidate No. 14 sleeve and one with Candidate No. 10 sleeve. These were installed in thermally protected bombs containing live M148 Adapter Boosters. In the other two bombs two live Fuzes M904E2 were installed, one with Candidate No. 14 and one with Candidate No. 10 sleeves. The bombs contained two inert M148 Adapter Boosters. In all cases the adapter rings were coated with Insunol; i.e., 30 mils intumescent paint and a 4 mil overcoat. The thermocouple arrangement was the same as in Fuze Test No. 23. The wind velocity was 0-4 knots throughout the entire test. Six and one-half inches of fuel were used in this test. The average burning time was computed to be twenty minutes.

Thirteen minutes thirty seconds (810 seconds) after the start of the fire the live Fuze M904E2 with Candidate No. 10 sleeve and the inert adapter booster reacted. The reaction was mild and from the fuze remnants recovered after the test the fuze appeared to deflagrate. Figure 118 shows the temperature vs time plot of the Fuze M904E2 thermocouples and Figure 119 represents the thermogram of the M148 Adapter Booster. Here again, the plateau is evident.

Fourteen minutes (840 seconds) after the fire was started the bomb containing the inert Nose Fuze M904E2 with the Candidate No. 14

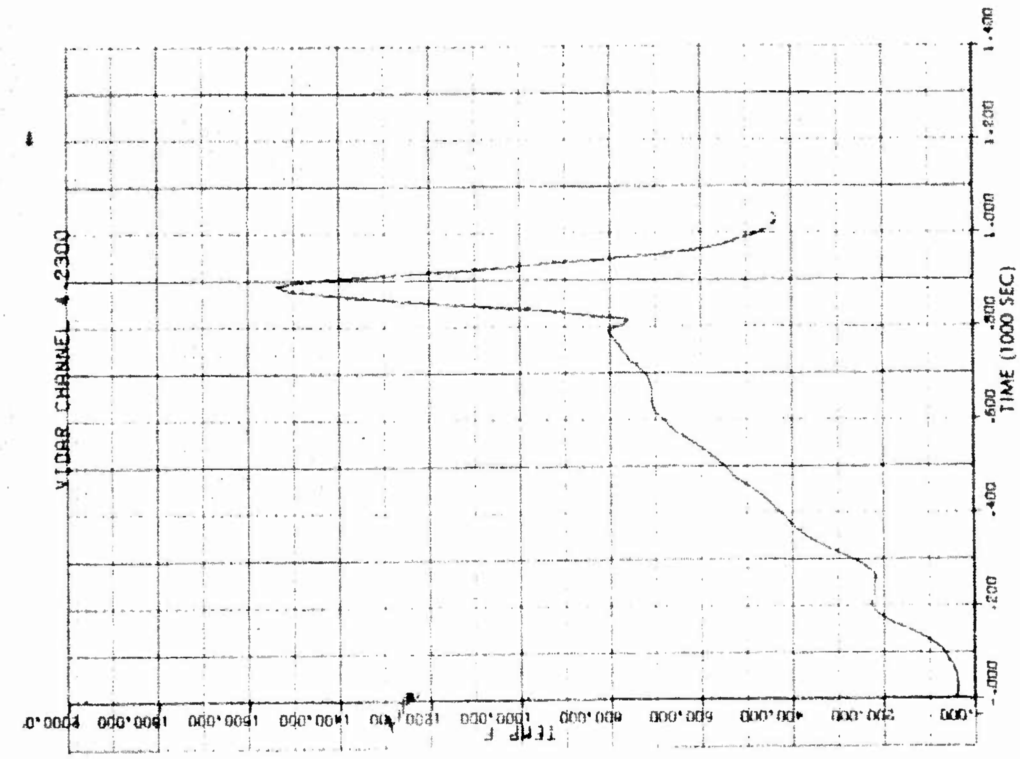


FIG. 116 FUZE TEST NO. 23 THERMOGRAM OF A LIVE M904E2 FUZE PROTECTED WITH A CANDIDATE NO. 1 SLEEVE

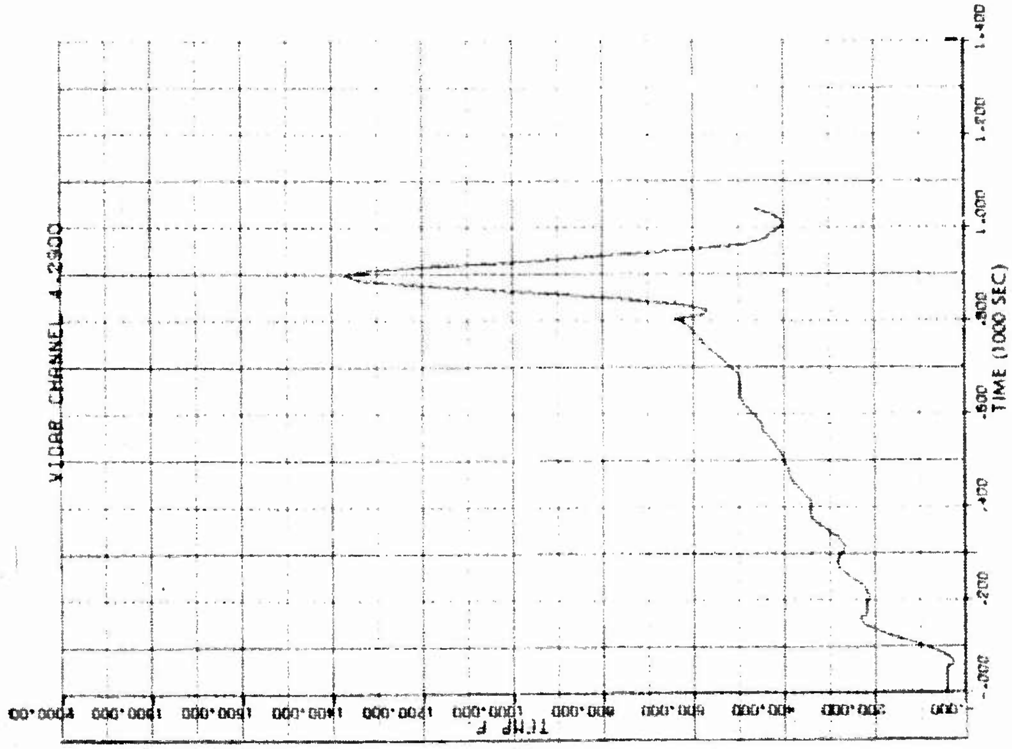


FIG. 117 FUZE TEST NO. 23 THERMOGRAM OF AN INERT M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

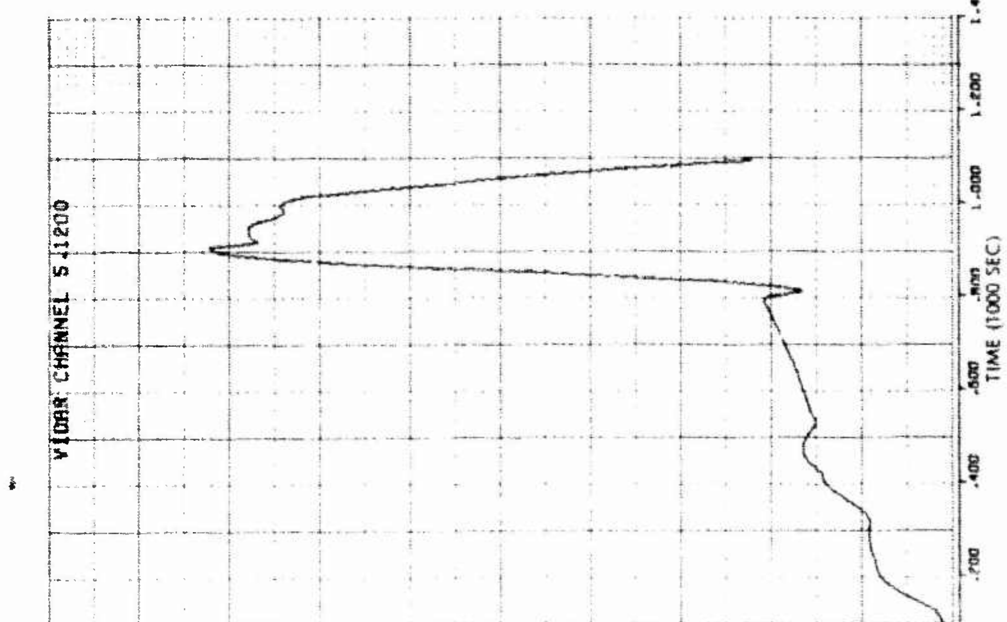


FIG. 118 FUZE TEST NO. 24 THERMOGRAM OF A LIVE M904E2 FUZE PROTECTED WITH A CANDIDATE NO. 10 SLEEVE

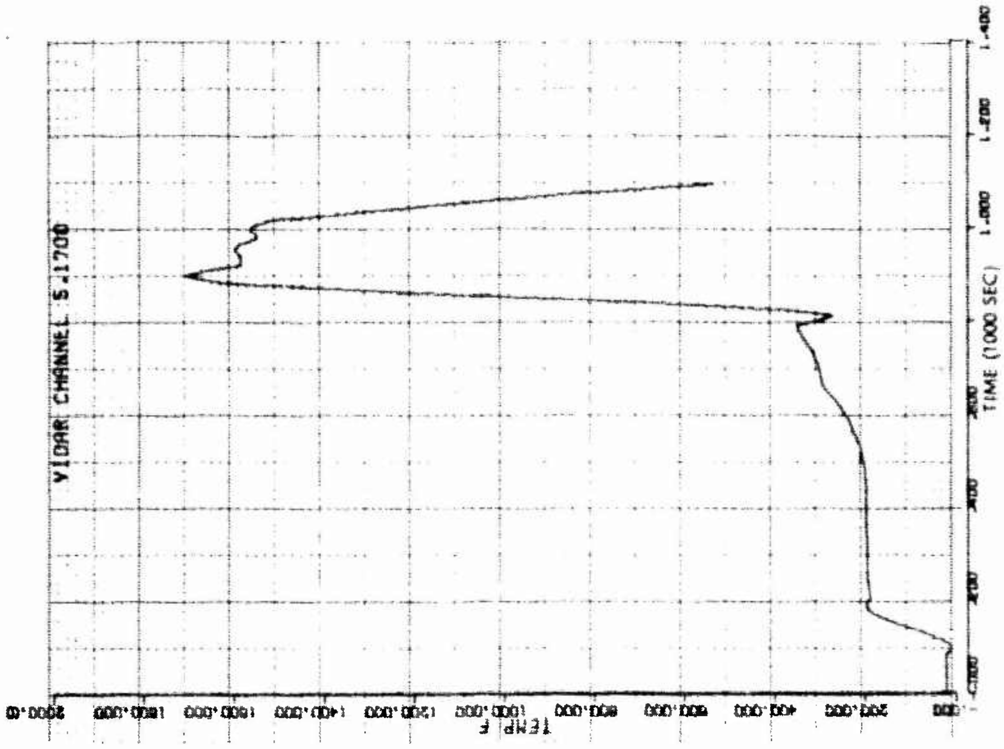


FIG. 119 FUZE TEST NO. 24 THERMOGRAM OF AN INERT M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 10 SLEEVE

sleeve and the live M148 Adapter Booster initiated. The reaction was rather mild and the fuze was recovered intact. Figures 120 and 121 represent typical thermograms of the fuze and adapter booster thermocouples, respectively.

The third reaction occurred fifteen minutes twenty seconds (920 seconds) after the initiation of the fuel originating from the inert Nose Fuze M904E2 protected with the Candidate No. 10 sleeve and Live M148 Adapter Booster. The reaction was mild and the fuze was also recovered. Figures 122 and 123 indicate typical thermograms for the fuze and booster.

The fourth reaction occurred fifteen minutes thirty-five seconds (935 seconds) after the start of the fire at the bomb containing a live Fuze M904E2 with Candidate No. 14 sleeve and inert M148 Adapter Booster. The reaction was mild and could not be audibly or visibly detected. The only indications were from the thermocouple records. Figures 124 and 125 indicate the fuze and booster ignition times. The fire temperature thermogram is shown in Figure 126.

These results indicate that Candidates No. 14 and No. 10 sleeves are promising as protective devices for the Fuze M904E2. The next two fuze shots were designed to choose the primary and back-up fixes.

Fuze Test No. 25

Four thermally protected inert concrete loaded bombs were again used, as in previous tests. One bomb contained a live Nose Fuze M904E2 protected with Candidate No. 1 sleeve. The M148 Adapter Booster was inert. The remaining three bombs contained inert Nose Fuzes M904E2 with Candidate No. 1, No. 14 and No. 10 sleeves assembled in Live M148 Adapter Boosters. All the sleeves were bonded to the fuze body with RTV 737.

The first reaction occurred thirteen minutes twenty seconds (800 seconds) after ignition of the fuel. The live Fuze M904E2 with the Candidate No. 1 sleeve and inert adapter booster reacted first. The reaction was rather mild, and the pieces of the adapter booster were recovered without major change. The wind velocity was 3-5 knots with occasional gusts up to eight knots. This was higher than in our previous experiments. As a result, the excursion of flame temperatures were larger than in our previous tests, and cook-off times were longer. Figure 127 indicates the variation of fire temperature with time. Figures 128 and 129 indicate the cook-off temperatures of the fuze and adapter booster.

The second reaction occurred fifteen minutes ten seconds (910 seconds) after the fuel ignition started and it was the bomb containing the inert Fuze M904E2 with the Candidate No. 1 sleeve and live M148 Adapter Booster. The reaction was mild and both fuze and adapter booster were recovered. The back of the adapter booster

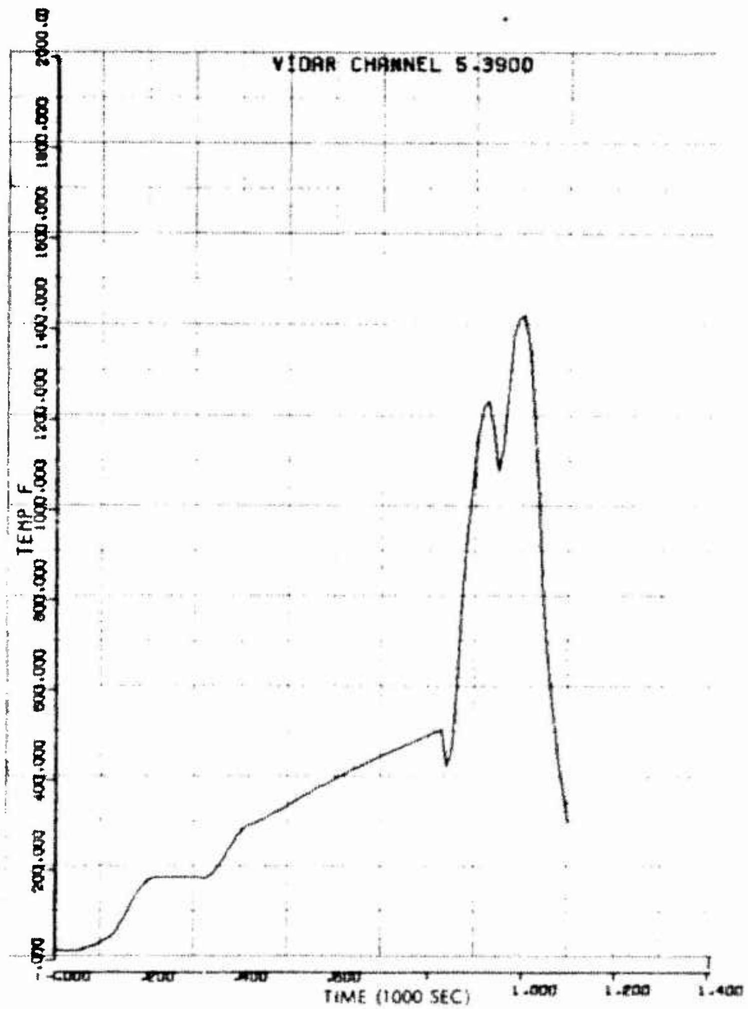


FIG. 120 FUZE TEST NO. 24 THERMOGRAM OF INERT M904E2 FUZE PROTECTED WITH CANDIDATE NO. 14 SLEEVE

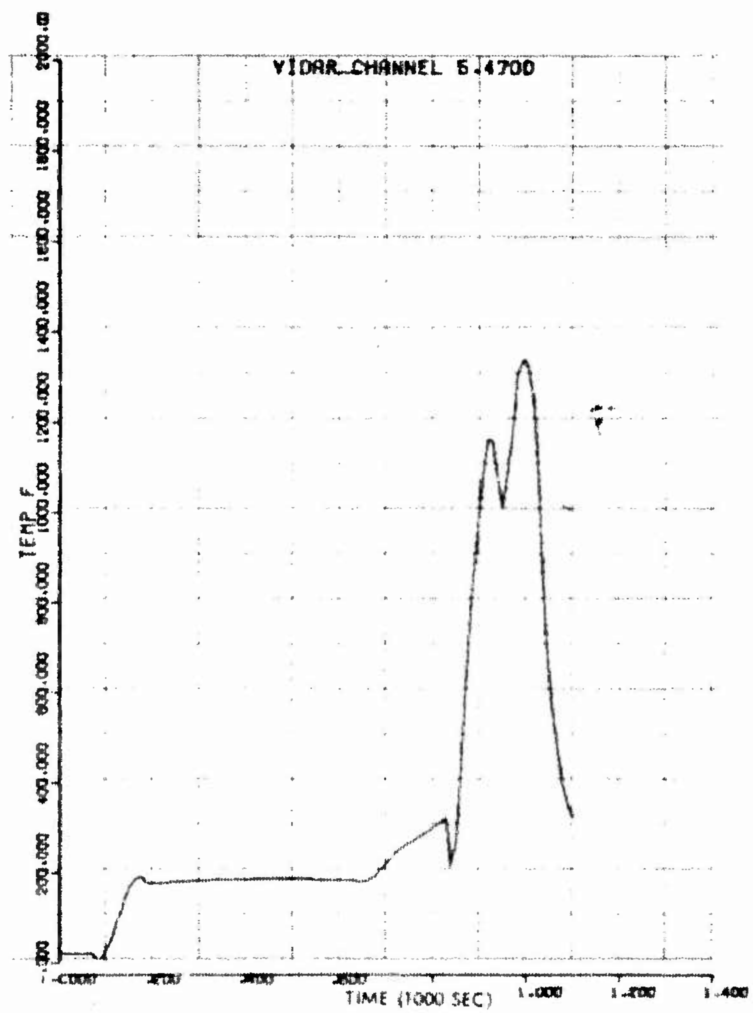


FIG. 121 FUZE TEST NO. 24 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING :1904E2 FUZE PROTECTED WITH CANDIDATE NO. 14 SLEEVE

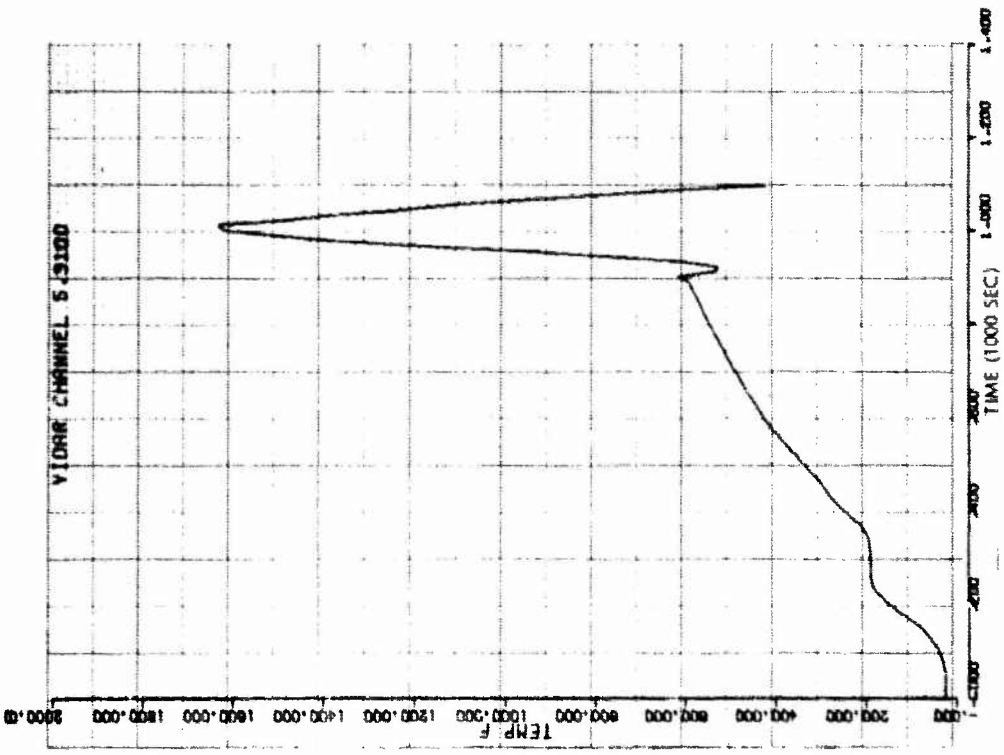


FIG. 122 FUZE TEST NO. 24 THERMOGRAM OF AN INERT M904E2 FUZE PROTECTED WITH CANDIDATE NO. 10 SLEEVE

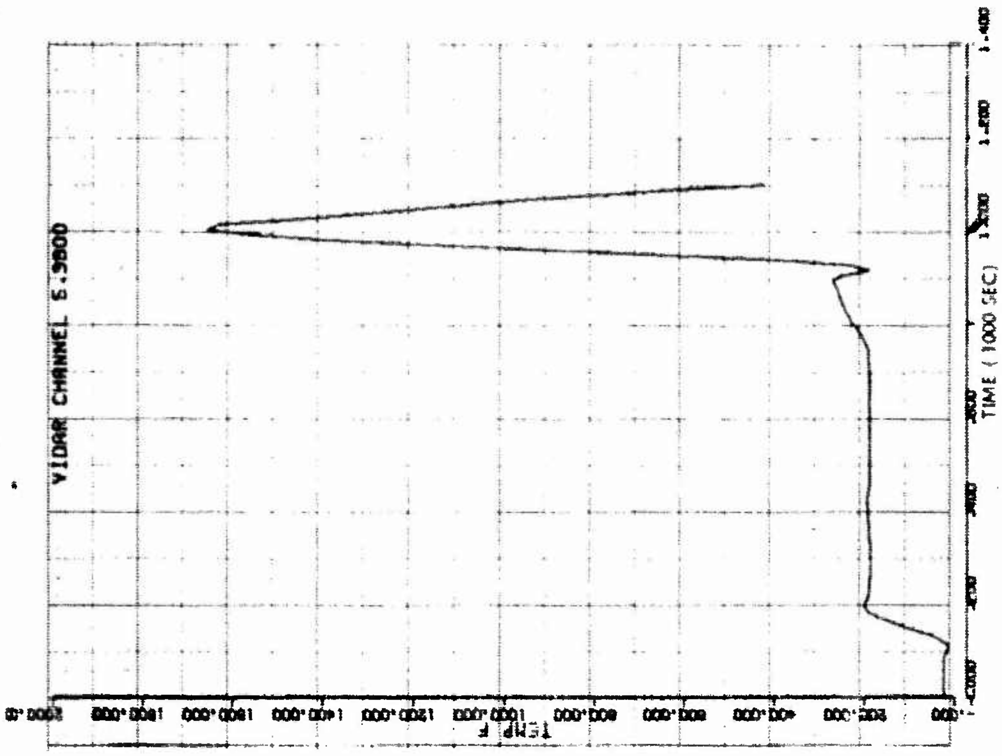


FIG. 123 FUZE TEST NO. 24 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 10 SLEEVE

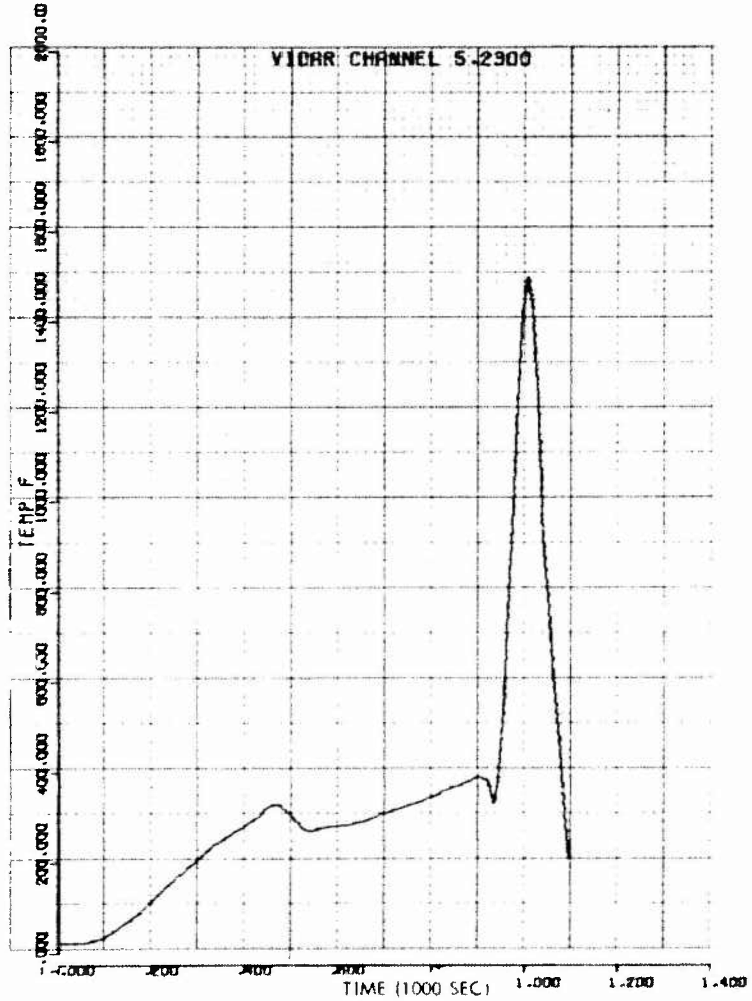


FIG. 124 FUZE TEST NO. 24 THERMOGRAM OF A LIVE M904E2 PROTECTED WITH CANDIDATE NO. 14 SLEEVE

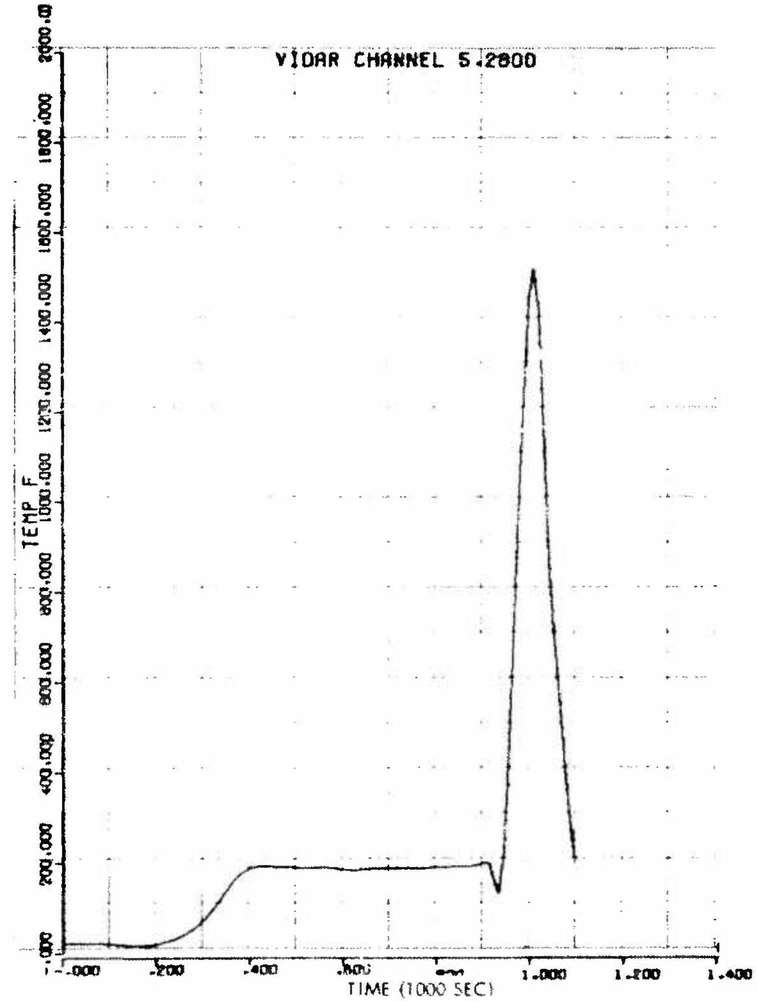


FIG. 125 FUZE TEST NO. 24 THERMOGRAM OF AN INERT M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 14 SLEEVE

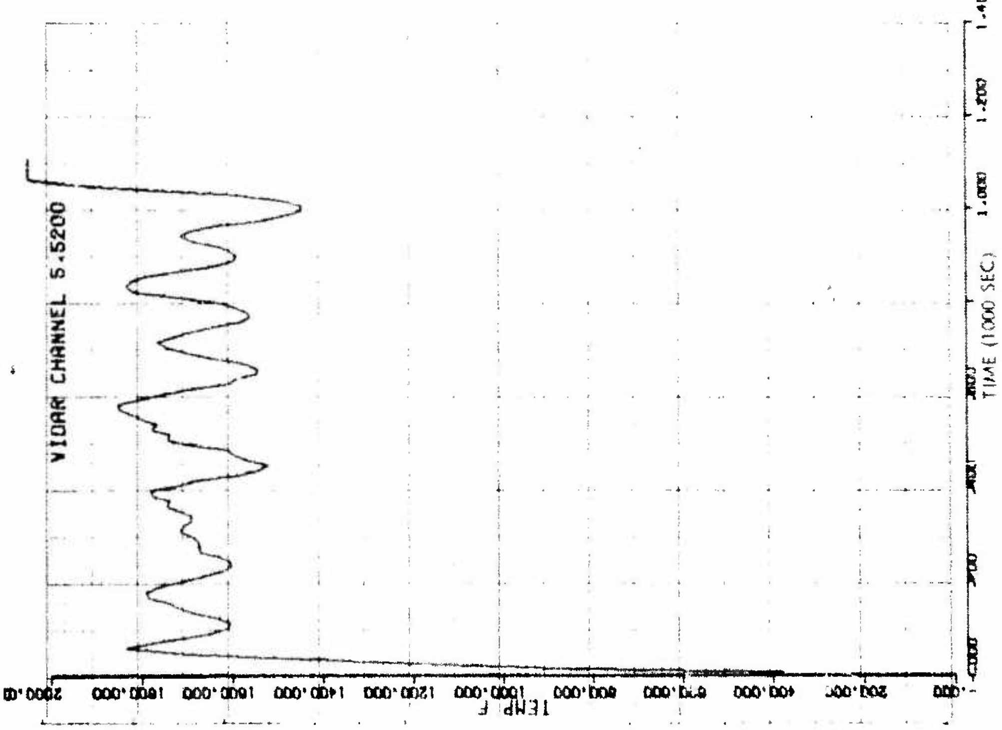


FIG. 126 FUZE TEST NO. 24 FIRE TEMPERATURE THERMOGRAM

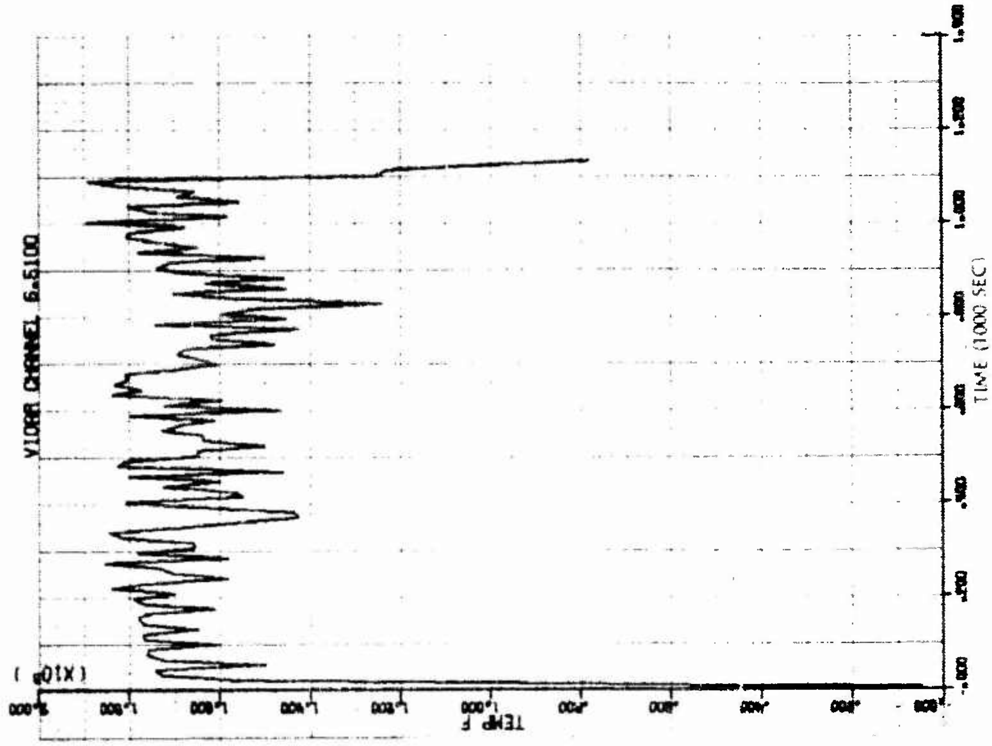


FIG. 127 FUZE TEST NO. 25 FIRE TEMPERATURE THERMOGRAM

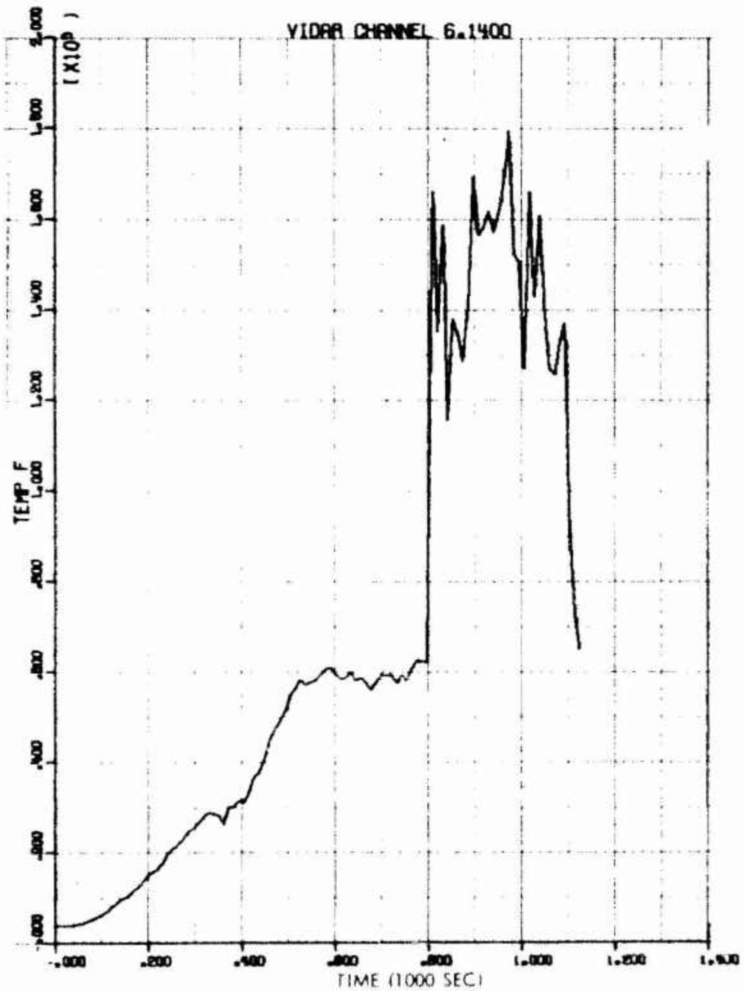


FIG. 128 FUZE TEST NO. 25 THERMOGRAM OF A LIVE M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

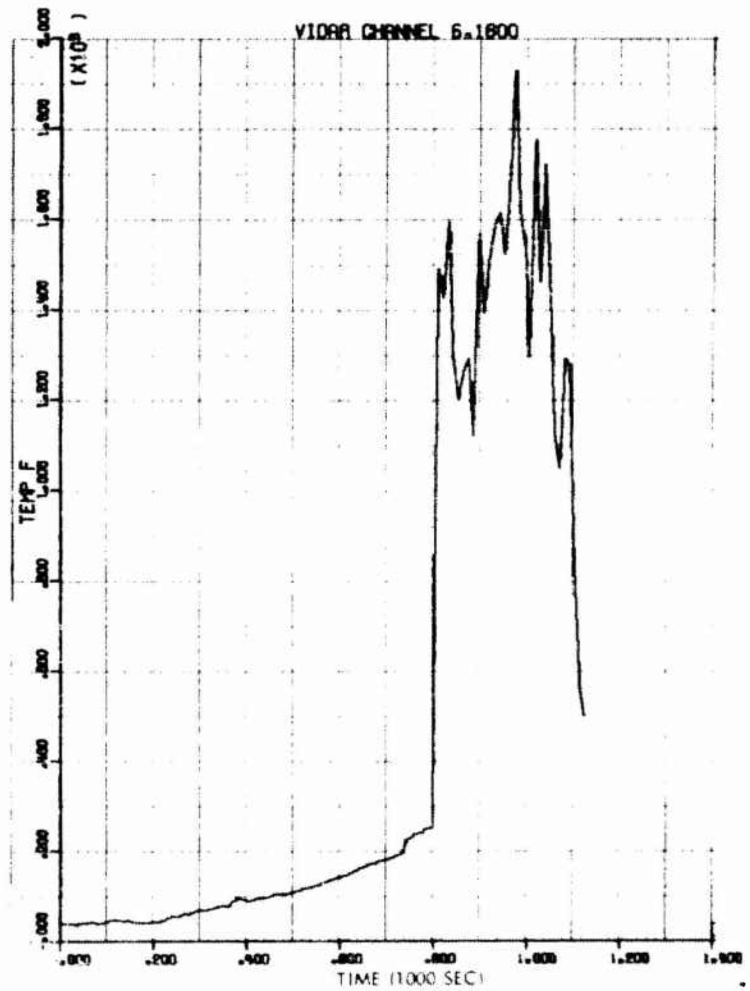


FIG. 129 FUZE TEST NO. 25 THERMOGRAM OF AN INERT M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

cup had a large hole, due to explosive burning. The time temperature plots for the fuze and adapter booster are shown in Figures 130 and 131.

The third reaction occurred at fifteen minutes forty seconds (940 seconds). This bomb contained a Fuze M904E2 with Candidate No. 14 sleeve assembled in a live M148 Adapter Booster. The reaction was a deflagration. The fuze was not recovered, however, the aluminum sleeve was still intact in the bomb. Figures 132 and 133 indicate the temperature of the fuze and adapter booster before and after ignition.

The fourth reaction involved the inert Fuze M904E2 with Candidate No. 10 sleeve assembled into a live M148 Adapter Booster. The reaction occurred seventeen minutes forty-five seconds (1065 seconds) after ignition of the fuel. The deflagration reaction was similar to those occurring in the assemblies. The temperature time thermogram for the fuze is shown in Figure 134. The temperature time curve for the adapter booster is shown in Figure 135.

These results indicate that the cook-off time of the fuze and the adapter booster can almost be doubled by means of a protective sleeving on the fuze and an intumescent paint system on the adapter booster.

At this time we were informed that Dow Corning no longer planned to market the RTV 737 because of production difficulties and RTV 3145 was proposed as a replacement. RTV 3145 evolves methyl alcohol on cure while RTV 737 releases acetic acid and this was considered desirable from a corrosion point of view.

Candidate No. 10 appeared to be attractive from a fire performance standpoint, however, the cost per sleeve was unattractive. Since the material is defined by a military specification alternate sources were contacted and new methods of manufacture resulted in a more favorable projected unit price. While these processing studies were in progress we were interested in determining whether the performance of the other two fixes (Candidate No. 1 and Candidate No. 14) would be affected by a change in the adhesive.

Fuze Test No. 26

Fuze Test No. 26 was designed to answer this question. Four thermally protected concrete loaded bombs were utilized. Two of the bombs were equipped with live Nose Fuzes M904E2 and inert M148 Adapter Boosters and two were equipped with inert Nose Fuzes M904E2 and live M148 Adapter Boosters. The Candidate No. 1 sleeves were bonded to the live fuze and the inert fuze by means of RTV 3145. The Candidate No. 14 protective sleeve were also bonded to the remaining two fuzes by means of RTV 3145. The fuzes and adapter boosters were instrumented identically as in the previous tests.

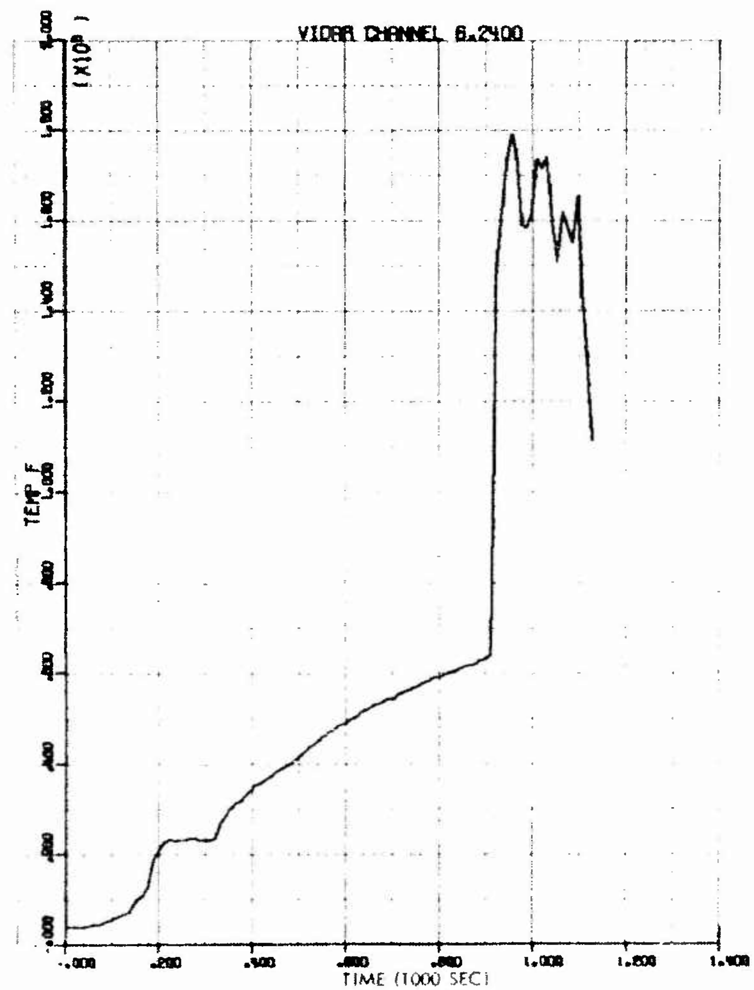


FIG. 130 FUZE TEST NO. 25 THERMOGRAM OF AN INERT M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

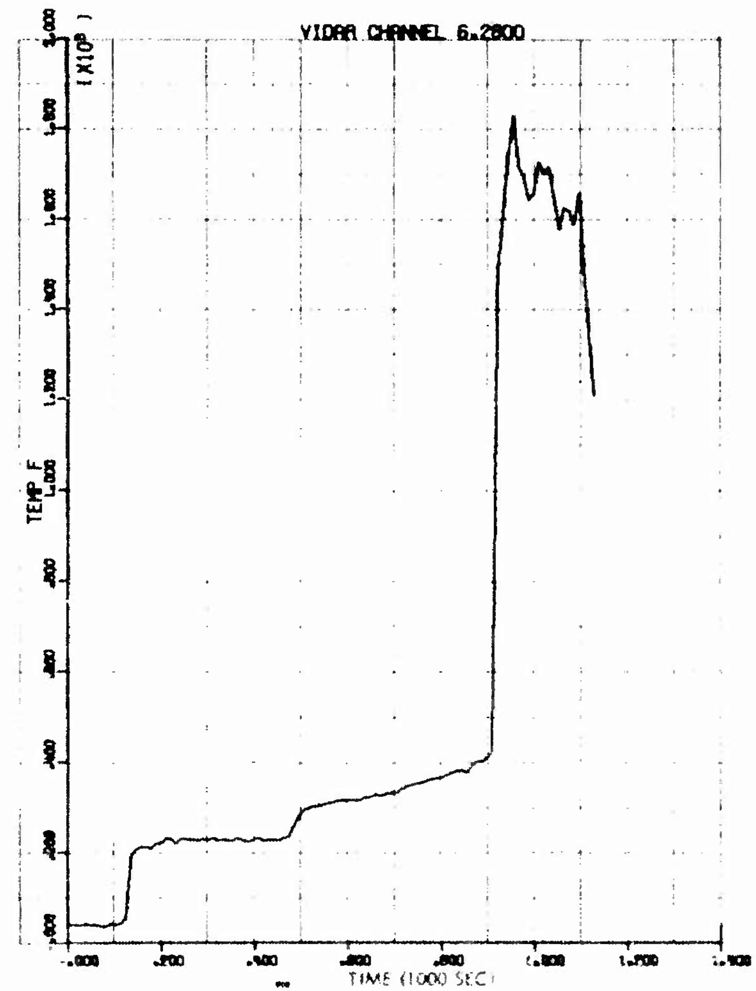


FIG. 131 FUZE TEST NO. 25 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

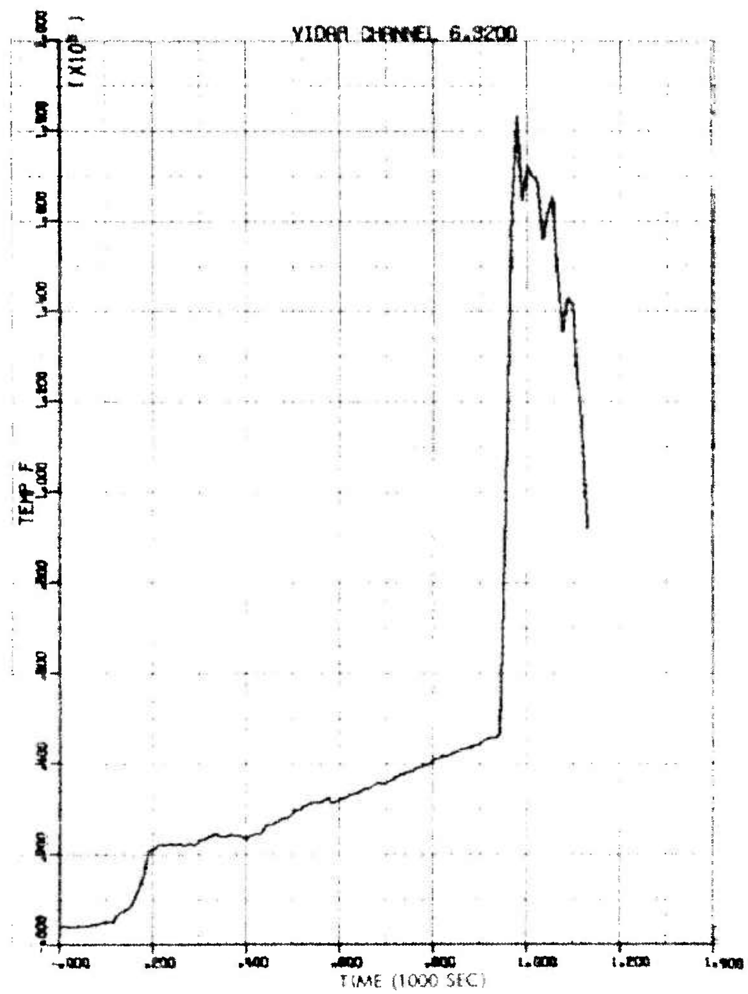


FIG. 132 FUZE TEST NO. 25 THERMOGRAM OF AN INERT M904E2 FUZE PROTECTED WITH CANDIDATE NO. 14 SLEEVE

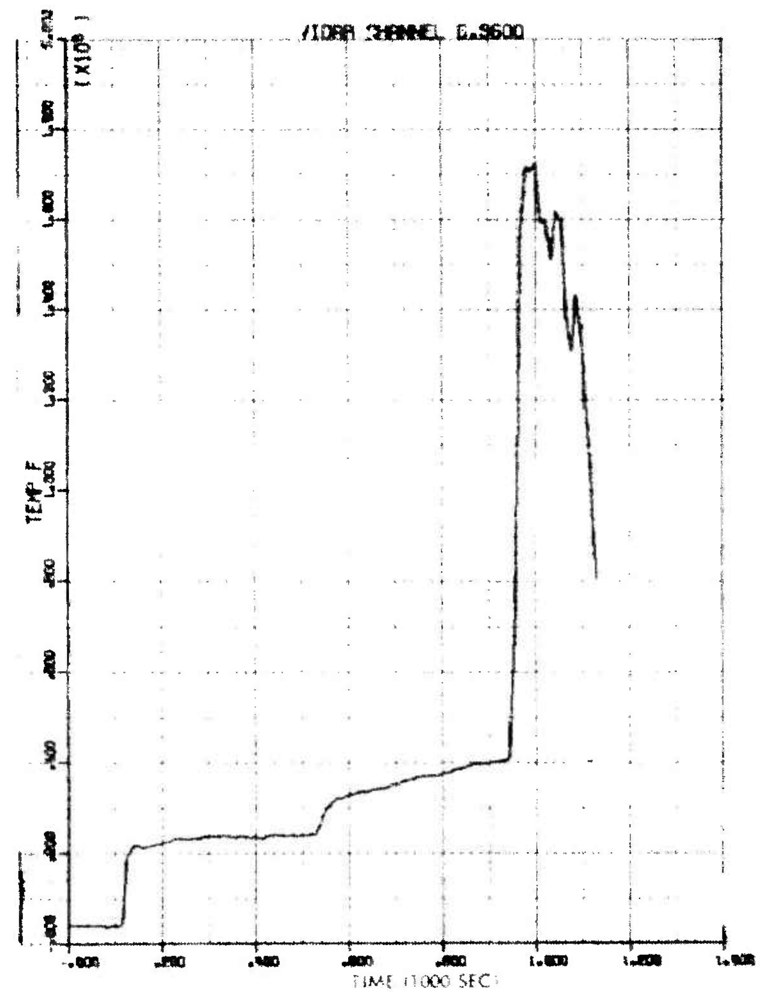


FIG. 133 FUZE TEST NO. 25 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 14 SLEEVE

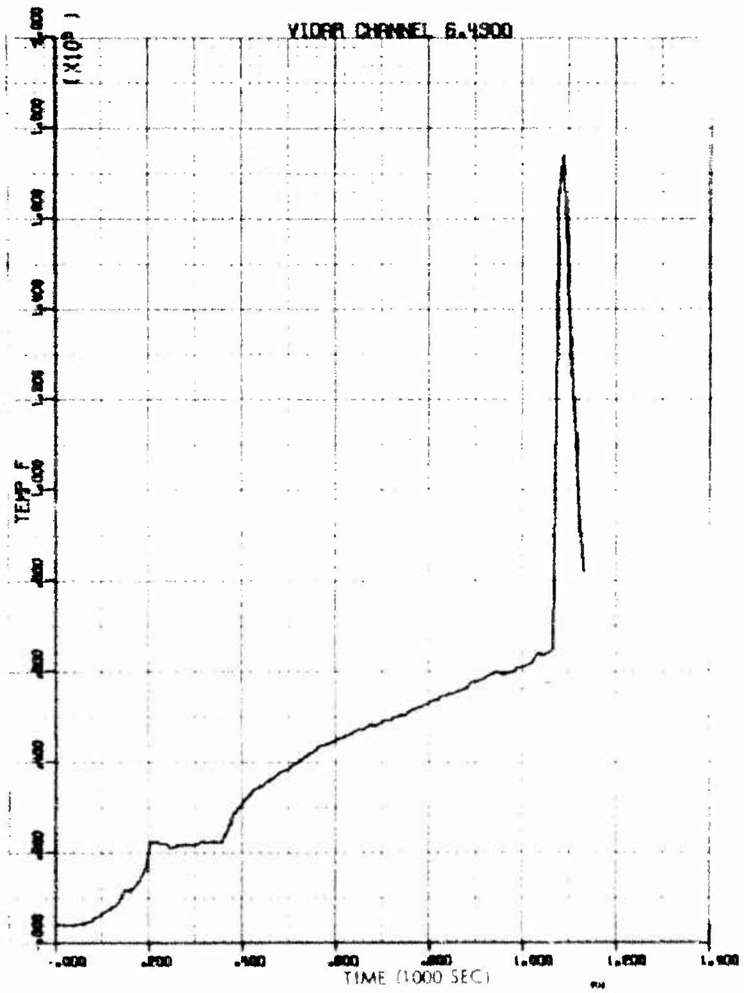


FIG. 134 FUZE TEST NO.25 THERMOGRAM OF AN INERT M904E2 FUZE PROTECTED WITH CANDIDATE NO. 10 SLEEVE

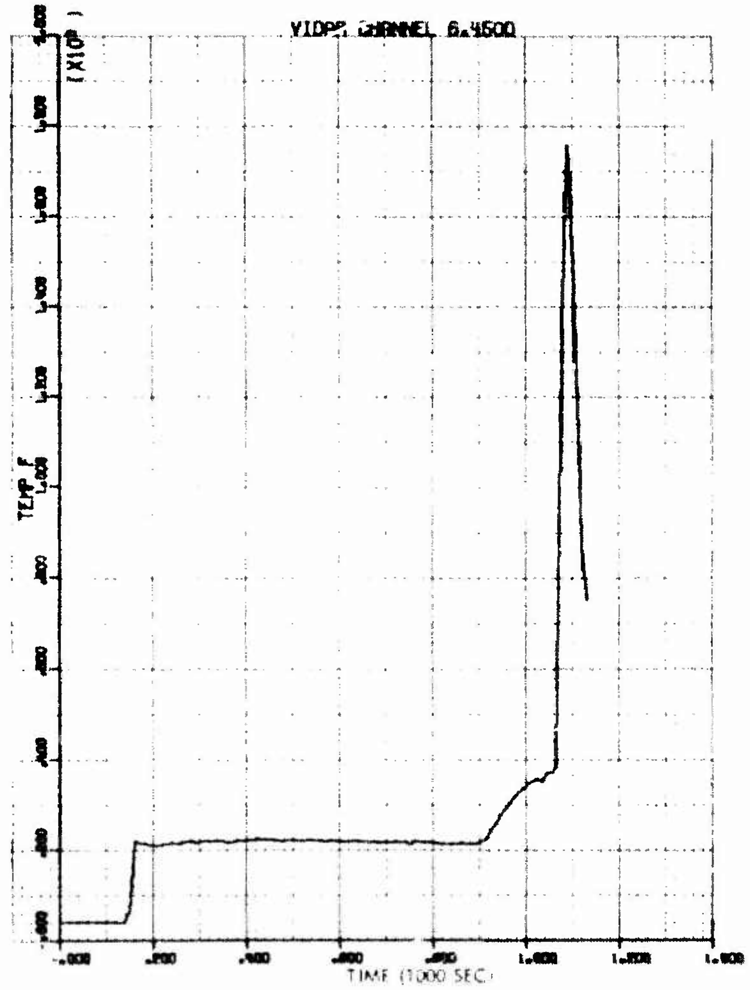


FIG. 135 FUZE TEST NO. 25 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO.10 SLEEVE

The first reaction occurred six minutes (360 seconds) after the start of the fire. The bomb containing a live Nose Fuze M904E2 with the Candidate No. 1 sleeve (bonded on with RTV 3145) and an inert adapter booster deflagrated. The fuze was not recovered. However, the adapter booster and bomb showed no sign of a detonation. Typical time temperature thermograms of the fuze and adapter booster are shown in Figures 136 and 137. The first peak in Figure 136 should be disregarded because of an imperfection in the magnetic tape.

The second reaction occurred twelve minutes ten seconds (730 seconds) after the start of the fire. This configuration consisted of a Candidate No. 1 sleeve bonded on an inert fuze with RTV 3145. A live adapter booster with a fixed adapter ring was used. Time temperature thermograms of the fuze and adapter thermocouples are shown in Figures 138 and 139.

The third reaction occurred with the Fuze M904E2 protected with Candidate No. 14 sleeve assembled in an inert M148 Adapter Booster deflagrated in twelve minutes forty-five seconds (765 seconds). The time temperature plots of the fuze and adapter booster thermocouples are shown in Figures 140 and 141.

The fourth reaction occurred in fifteen minutes fifteen seconds (915 seconds). The bomb contained an inert Nose Fuze M904E2 with Candidate No. 14 sleeve and a live M148 Adapter Booster. The reaction was a deflagration and was exceedingly mild. The nose fuze was recovered intact. Typical thermograms of the fuze and adapter booster are shown in Figures 142 and 143. The first peak in Figure 142 should be disregarded because of an imperfection in the tape. The fire temperature thermogram is shown in Figure 144.

These results are summarized in Table 21. It can be seen that the cook-off time of the Fuze M904E2, protected with a Candidate No. 1 sleeve, is markedly dependent upon the adhesive which is used to attach the device to the fuze. The Candidate No. 14 sleeve appears to be only slightly affected by the change in adhesive. The adapter booster with the Insunol on the adapter ring seems to be unaffected by the adhesive which is used on the nose fuze. As a result of this test the Candidate No. 1 material was eliminated from the program since insufficient time or funding was available for further testing of various adhesives. The Candidate No. 10 sleeve produced by another source per specification WS-8939 was continued since as stated previously the projected cost by a new manufacturing method was attractive.

In order to check the material a small scale fire test was performed on a sheet of the Candidate No. 10 material obtained from the new source. No difference in thermal protection could be detected from material obtained from either source. Sleeves were then fabricated by the new source for assembly on Fuzes M904E2.

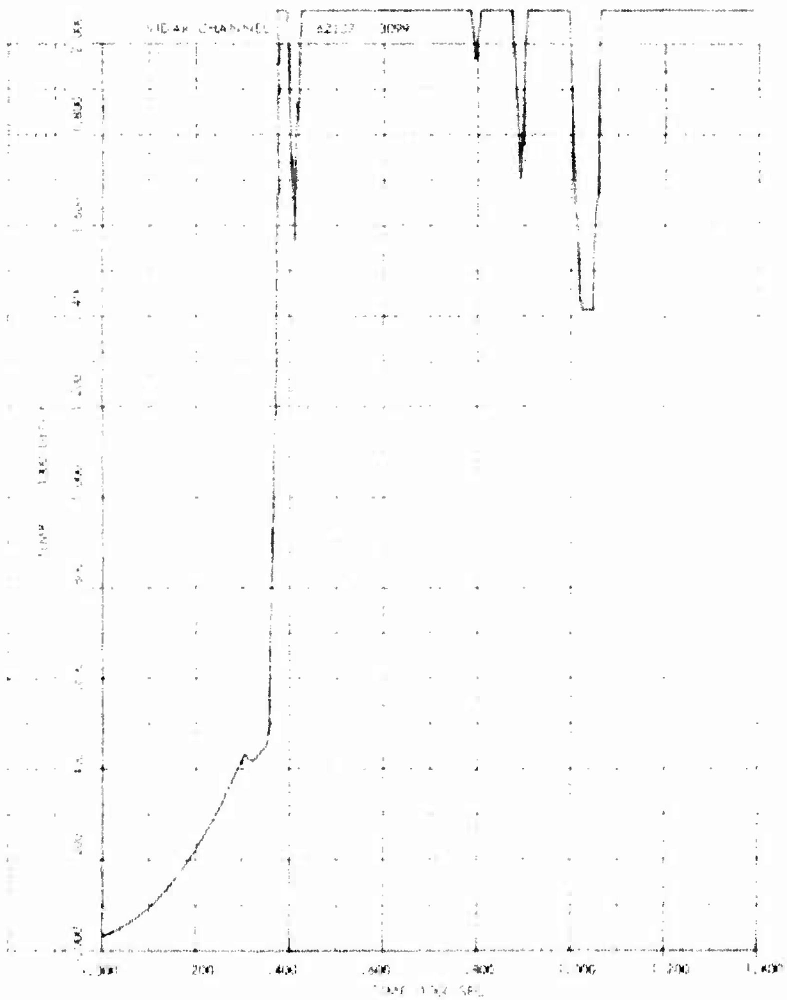


FIG. 136 FUZE TEST NO. 26 THERMOGRAM OF A LIVE M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE BONDED ON WITH RTV 3145

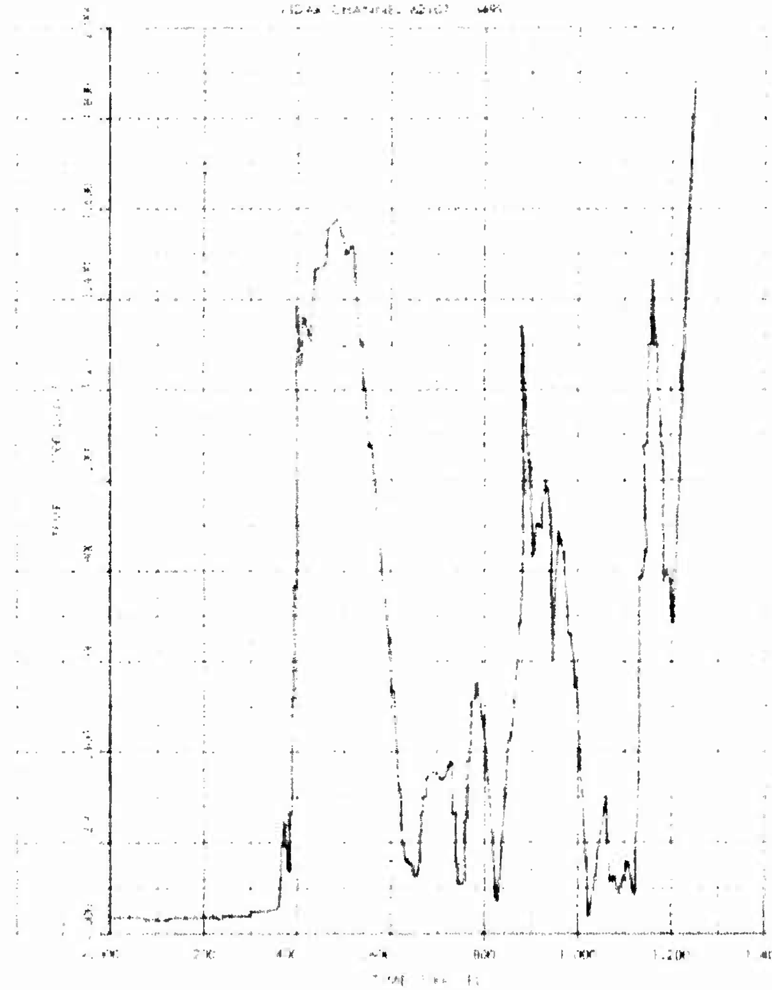


FIG. 137 FUZE TEST NO. 26 THERMOGRAM OF AN INERT M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

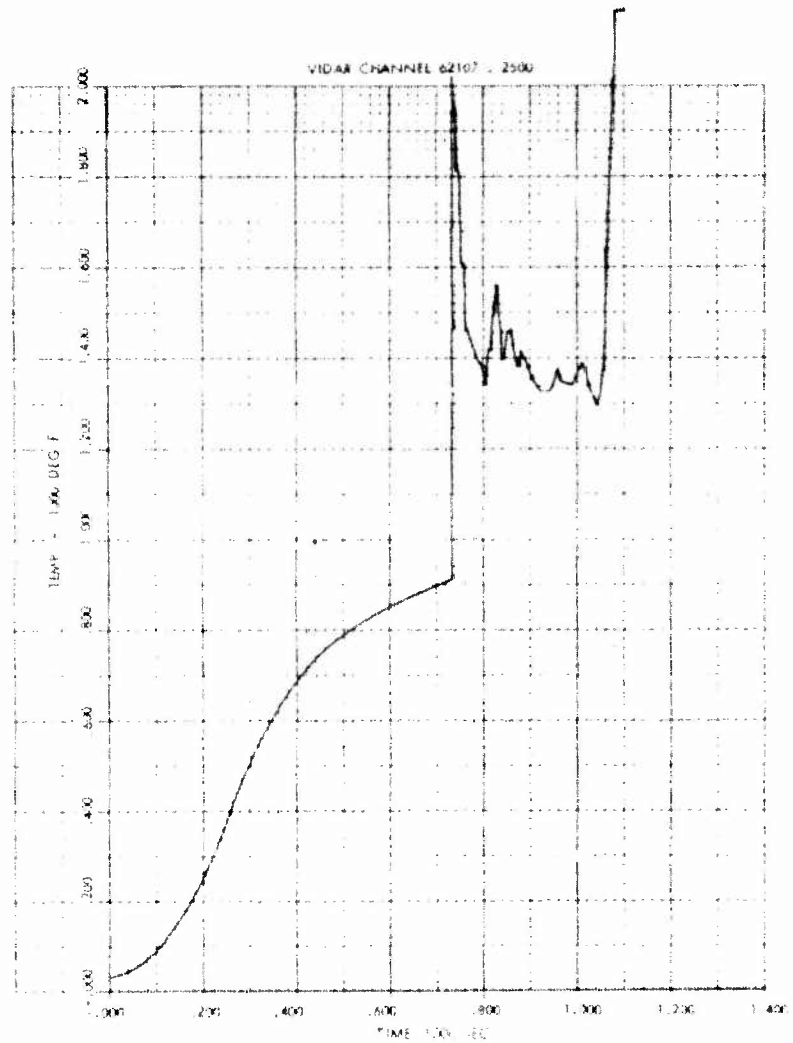


FIG. 138 FUZE TEST NO. 26 THERMOGRAM OF AN INERT M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE BONDED ON WITH RTV 3145

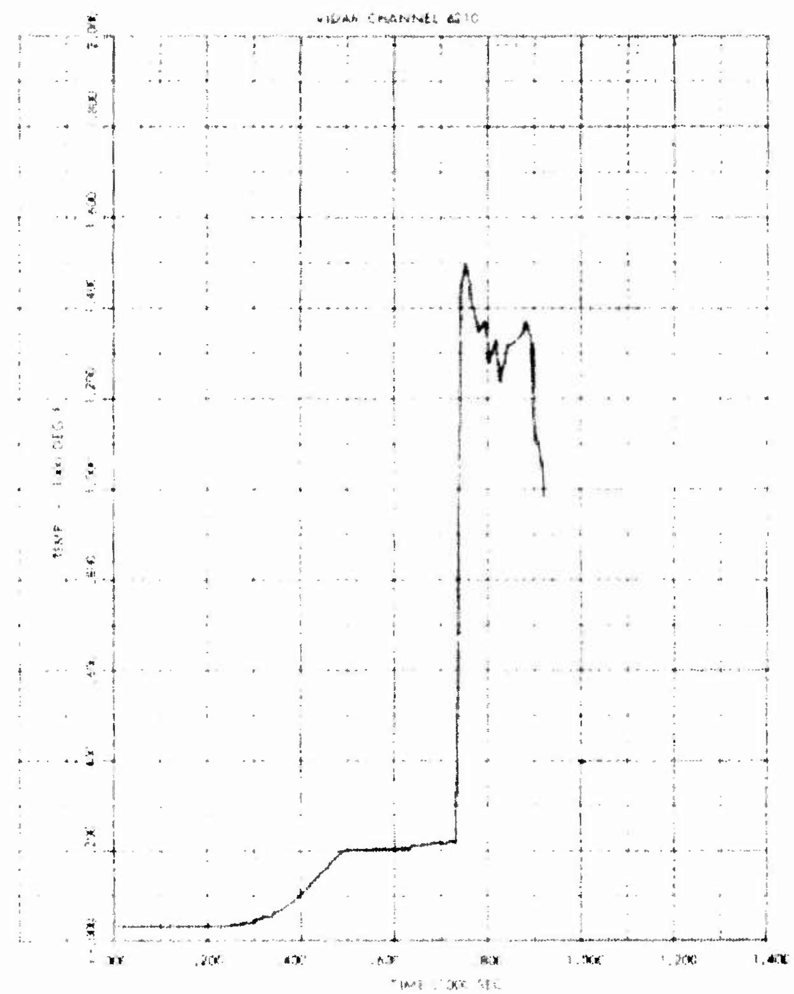


FIG. 139 FUZE TEST NO. 26 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE BONDED WITH RTV 3145

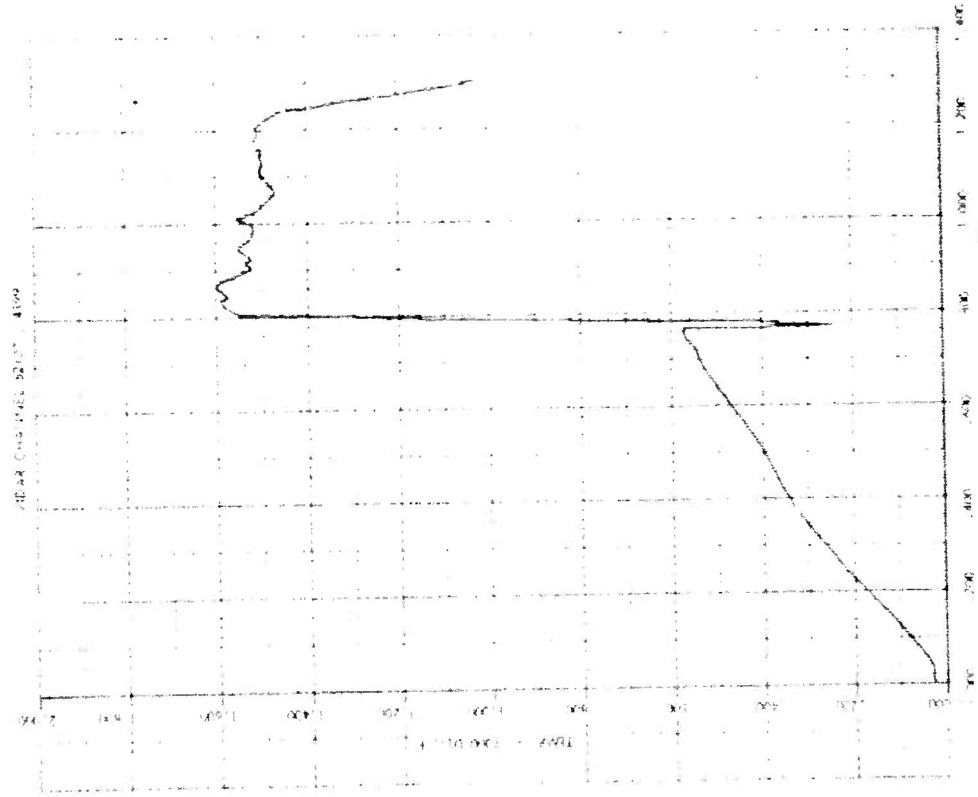


FIG. 140 FUZE TEST NO. 26 THERMOGRAM OF A LIVE M904E2 FUZE PROTECTED WITH CANDIDATE NO. 14 SLEEVE BONDED WITH RTV 3145

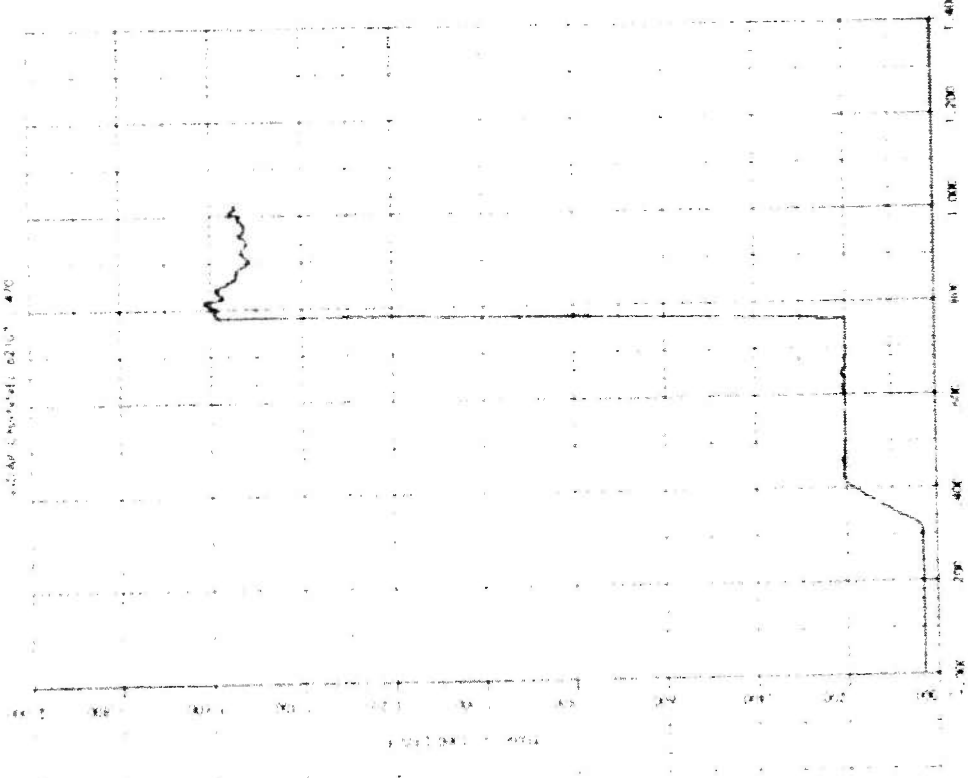


FIG. 141 FUZE TEST NO. 26 THERMOGRAM OF AN INERT M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 1 SLEEVE

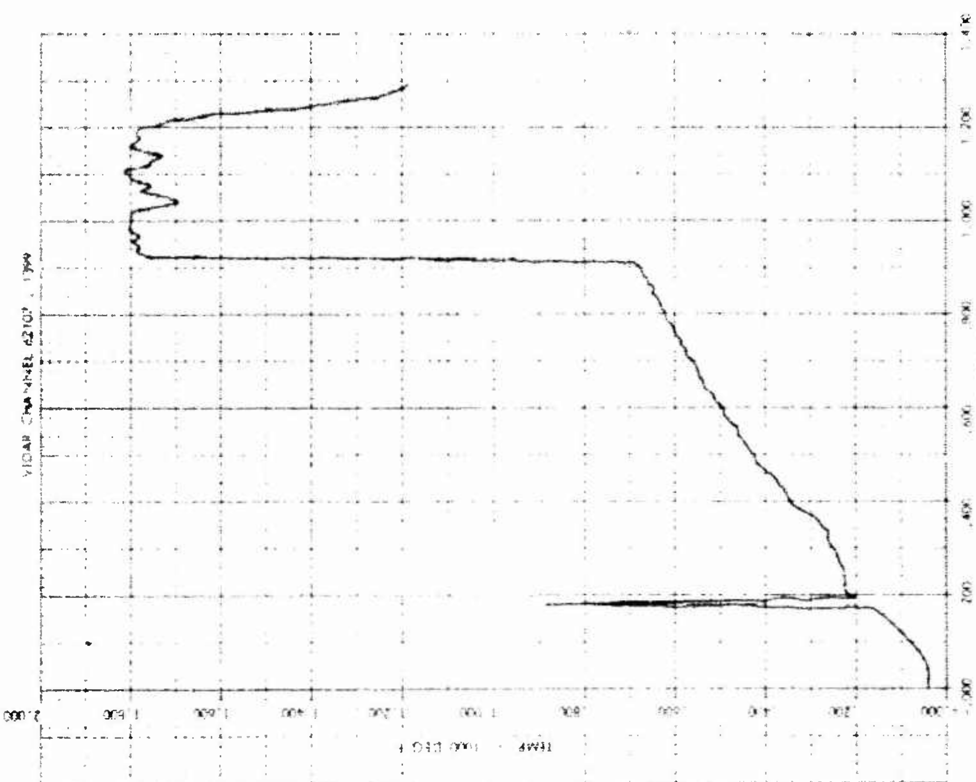


FIG. 142 FUZE TEST NO. 26 THERMOGRAM OF AN INERT M904E2 FUZE PROTECTED WITH CANDIDATE NO. 14 SLEEVE BONDED WITH RTV 3145

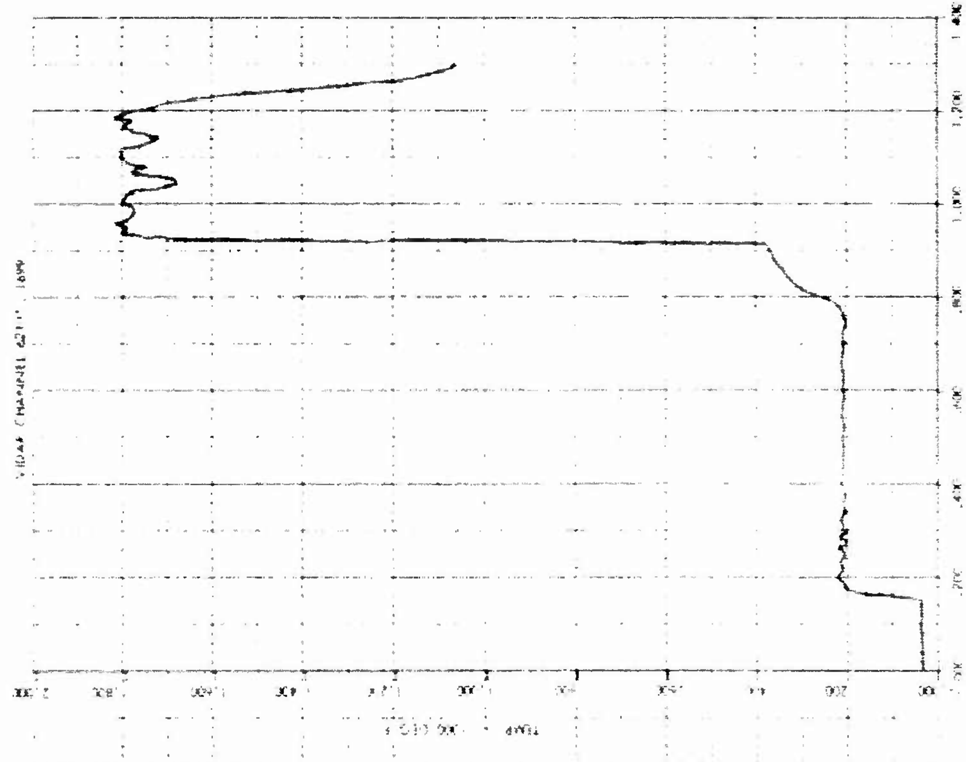


FIG. 143 FUZE TEST NO. 26 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 14 SLEEVE BONDED WITH RTV 3145

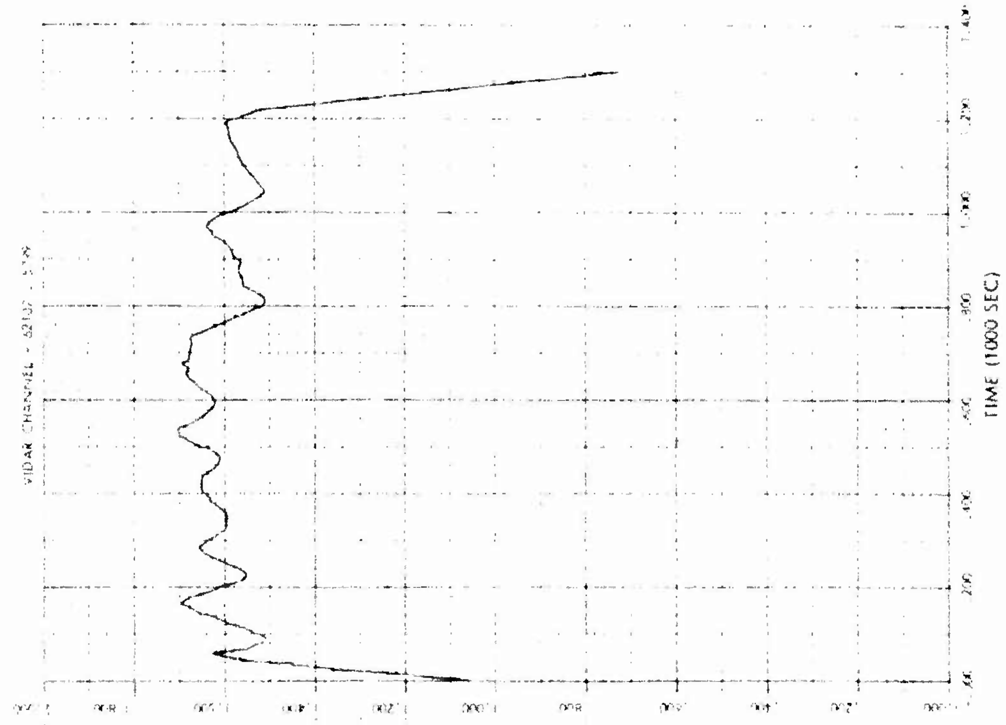


FIG. 144 FUZE TEST NO. 26 FIRE TEMPERATURE THERMOCOUPLE

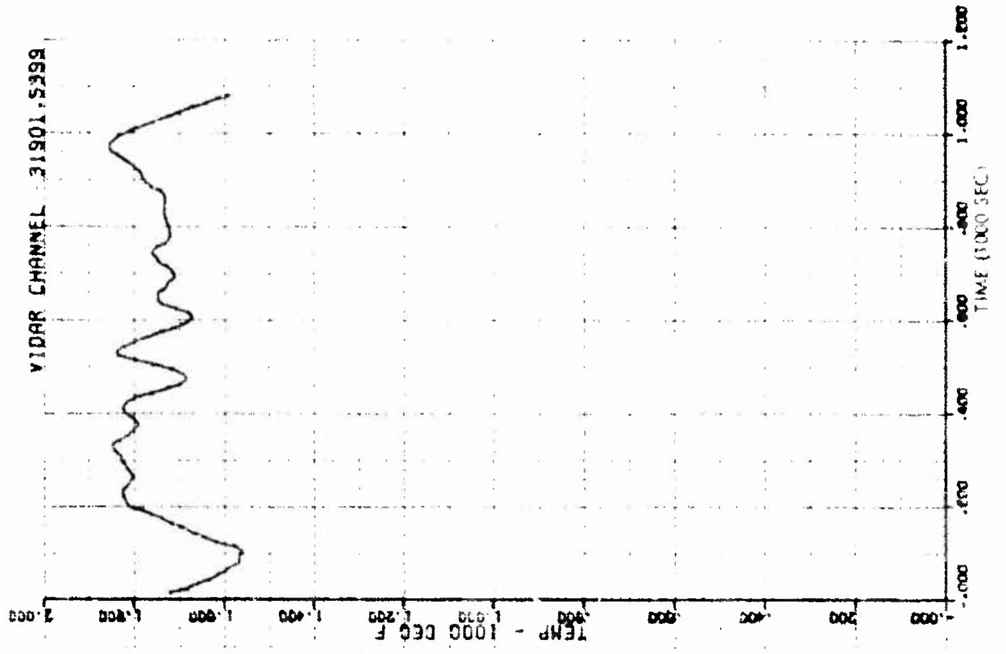


FIG. 145 FUZE TEST NO. 27 FIRE TEMPERATURE THERMOCOUPLE

Table 21

Cook-Off Results on Thermally Protected Concrete Loaded MK82 Bombs Containing Live and Inert Nose Fuzes M904E2 with Various Protective Coverings Assembled in Live and Inert M148 Adapter Boosters

Fuze Test No.	Nose Fuze Configuration	Adapter Booster Configuration	Reaction Time Sec.	Type of Reaction
23	Live M904E2 with Candidate No. 1 and RTV 737	Inert T45E7 with Insunol on adapter ring	590	Deflagration
23	Inert M904E2 with Candidate No. 1 and RTV 737	Live T45E7 with Candidate No. 1 on adapter ring	625	Detonation
23	Inert M904E2 with Candidate No. 1 and RTV 737	Live T45E7 with Insunol on adapter ring	710	Deflagration
23	Live M904E2 with Candidate No. 1 sleeve and RTV 737	Inert T45E7 with disc of Candidate No. 1 material on adapter ring	810	Deflagration
24	Live M904E2 with Candidate No. 10 and RTV 737	Inert T45E7 with Insunol on adapter ring	810	Deflagration
24	Inert M904E2 with Candidate No. 14 and RTV 737	Live T45E7 with Insunol on adapter ring	840	Deflagration
24	Inert M904E2 with Candidate No. 10 and RTV 737	Live T45E7 with Insunol on adapter ring	920	Deflagration
24	Live M904E2 with Candidate No.14 and RTV 737	Inert T45E7 with Insunol on Adapter ring	935	Deflagration
25	Live M904E2 with Candidate No. 1 and RTV 737	Inert T45E7 with Insunol on adapter ring	800	Deflagration
25	Inert M904E2 with Candidate No. 1 and RTV 737	Live T45E7 with Insunol on adapter ring	910	Deflagration
25	Inert M904E2 with Candidate No. 14 and RTV 737	Live T45E7 with Insunol on adapter ring	940	Deflagration

Table 21 (Con't.)

Fuze Test No.	Nose Fuze Configuration	Adapter Booster Configuration	Reaction Time Sec.	Type of Reaction
25	Inert M904E2 with Candidate No. 10 and RTV 737	Live T45E7 with Insunol on adapter ring	1065	Deflagration
26	Live M904E2 with Candidate No. 1 and RTV 3145	Inert T45E7 with Insunol on adapter ring	360	Deflagration
26	Inert M904E2 with Candidate No. 1 and RTV 3145	Live T45E7 with Insunol on adapter ring	730	Deflagration
26	Live M904E2 with Candidate No. 14 and RTV 3145	Inert T45E7 with Insunol on adapter ring	765	Deflagration
26	Inert M904E2 with Candidate No. 14 and RTV 3145	Live T45E7 with Insunol on adapter ring	915	Deflagration

Fuze Test No. 27

The next series of tests were combined tests. The first test contained a Candidate No. 10 sleeve on a Nose Fuze M904E2 with a fixed inert M148 Adapter Booster and an Inert Fuze M904E2 with a Candidate No. 10 sleeve in a live fixed M148 Adapter Booster. The other two thermally protected bombs contained live Candidate No. 14 M904E2 fixed Nose Fuzes with live fixed M148 Adapter Boosters. All of the adapter boosters were equipped with a steel disc .027" thick coated on both sides with .034" of Insunol including overcoat. The aluminum sleeve was coated on the top surface and inside surface with .034" of Insunol including overcoat. The front of the adapter ring also was coated with .034" of Insunol including overcoat. The adapter boosters contained thermocouples in the same position as in our previous tests. No thermocouples were placed on the fuze.

The first reaction occurred in seven minutes fifty-five seconds (475 seconds) after ignition of the fuel. The Fuze M904E2 with Candidate No. 14 assembled in a live M148 Adapter Booster deflagrated. The adapter booster cup had a large hole burned in the rear, however, the Mk 82 Bomb was still intact and there was no damage to the bomb. From the thermocouple data it appears as though the fuze deflagrated since no self-heating appeared to have taken place in the adapter booster. A typical fire temperature thermogram is shown in Figure 145. The thermogram for the Adapter Booster is shown in Figure 146.

The second reaction occurred at the bomb containing the fixed inert Fuze M904E2 with Candidate No. 10 sleeve with the fixed live M148 Adapter Booster. The reaction occurred fifteen minutes twenty seconds (920 seconds) after ignition of the fire. The reaction was a deflagration. One can see from the thermogram in Figure 147 the evidence of self-heating of the tetryl in the adapter booster shortly before ignition.

The Fuze M904E2 with Candidate No. 14 sleeve in a live M148 Adapter Booster reacted next at fifteen minutes fifty seconds (950 seconds) after ignition of the fuel. The reaction was a deflagration and appears to have originated in the fuze. A typical thermogram is shown in Figure 148. The rapid rise before ignition is missing in these thermograms.

The live Nose Fuze M904E2 with Candidate No. 10 sleeve in an inert sand filled M148 Adapter Booster reacted next after seventeen minutes (1020 seconds). The reaction was mild and was considered a deflagration. A typical thermogram of the inert booster adapter is shown in Figure 149.

Because of the short reaction time taking place with the fuze containing the Candidate No. 14 sleeve and fixed live adapter booster, it was decided to repeat this test utilizir ~nly live adapter boosters and live fuzes. The live adapter ~sters and live

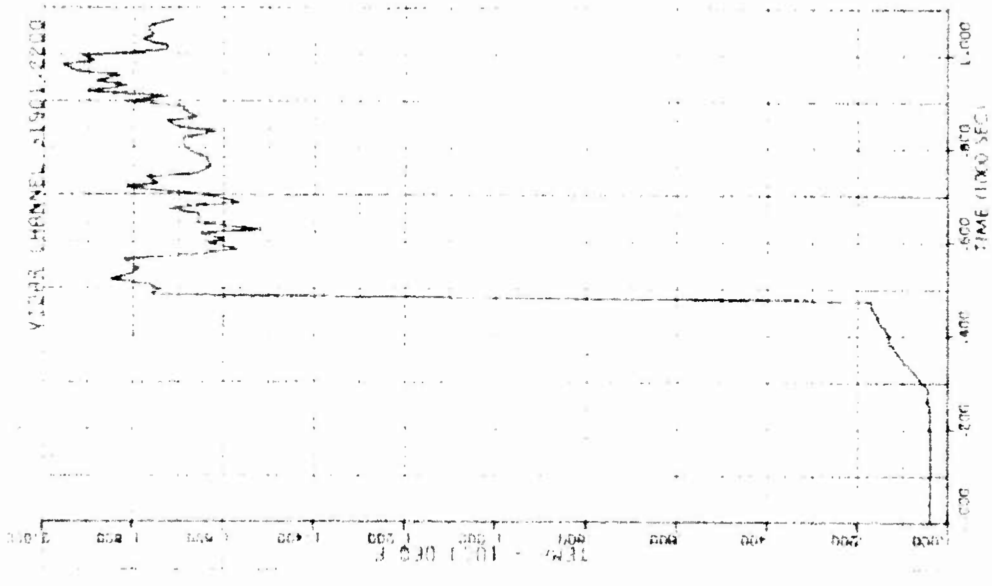


FIG. 146 FUZE TEST NO. 27 THERMOGRAM OF LIVE M148 ADAPTER BOOSTER CONTAINING FUZE M904E2 PROTECTED WITH CANDIDATE NO. 10 SLEEVE MANUFACTURED BY A NEW SOURCE

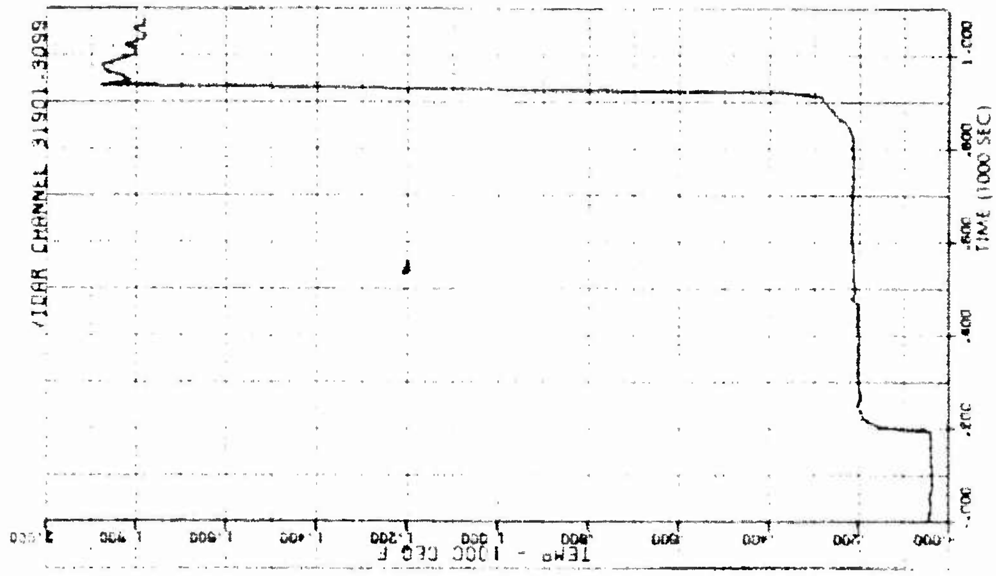


FIG. 147 FUZE TEST NO. 27 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH A CANDIDATE NO. 10 SLEEVE FROM A NEW SOURCE

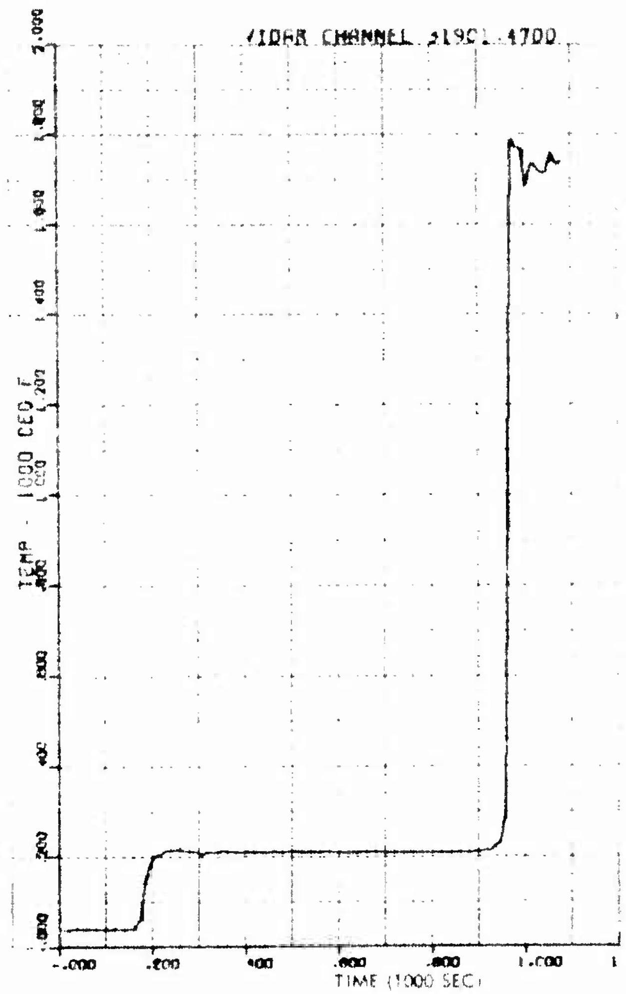


FIG. 148 FUZE TEST NO. 27 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING FUZE M904E2 PROTECTED WITH CANDIDATE NO. 10 SLEEVE FROM A NEW SOURCE

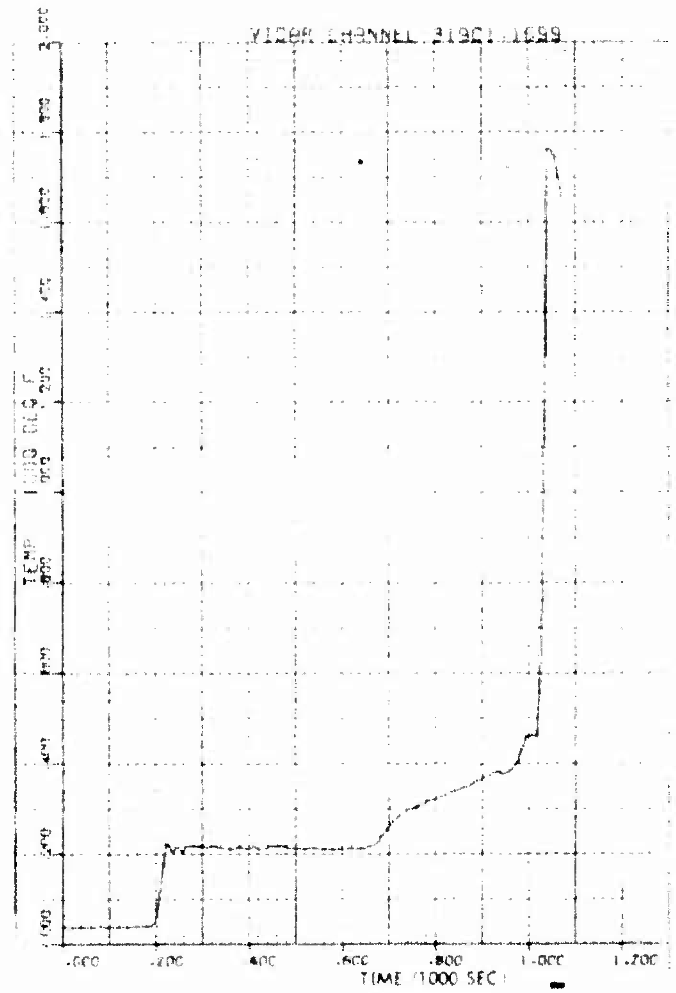


FIG. 149 FUZE TEST NO. 27 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 10 SLEEVE FROM A NEW SOURCE

nose fuzes were tested together in order to determine the compatibility of the open adapter fixes with the live fuze fixes. Two tests were planned in this study due to fund limitations and scheduling limitations.

Fuze Test No. 28

Concrete loaded bombs were coated with Insunol intumescent paint on the exterior surface. All adapter rings were also painted with Insunol (.034" thick including overcoat). All live M148 Adapter Boosters were equipped as before with a .027" thick steel disc coated on both sides with .030" thick intumescent paint plus .004" overcoat. The aluminum sleeve was coated on the top and inside surfaces with Insunol .034" thick. All protective sleeves were cemented to the fuzes (using RTV 3145), allowing forty-eight hours drying time before testing. Thermocouples were installed in the usual fashion, in contact with the explosive and in the rear booster cavity.

Seven minutes fifty seconds (475 seconds) after the beginning of the fire the Fuze M904E2 protected with Candidate No. 14 sleeve deflagrated. The reaction was mild. A photograph of the pit after the test is shown in Figure 150. The reaction appears to have originated in the fuze, judging from the appearance of the adapter booster curve shown in Figure 151. The average fire temperatures was 1650°F and is comparable with the other fuze test.

The second reaction (deflagration) occurred eight minutes (480 seconds) after the ignition of the fuel. The Fuze M904E2 was protected with a Candidate No. 10 sleeve. Again the reaction appears to have originated in the fuze section from the appearance of the thermocouple thermogram shown in Figure 152.

The third reaction occurred nine minutes (540 seconds) after ignition of the fuel. The reaction took place at the bomb equipped with the Candidate No. 14 sleeve. The bomb jetted like a rocket for approximately thirty seconds. The fuze body was recovered with the protective sleeving still cemented to the fuze body. A close-up of the ablated sleeve is shown in Figure 153. The reaction is believed to have originated in the fuze. The adapter booster thermocouple trace is shown in Figure 154.

The fourth reaction occurred on the assembly with Candidate No. 10 sleeve on Fuze M904E2 fourteen minutes thirty seconds (870 seconds) after the ignition of the fuel. The reaction was a deflagration. The fuze was recovered outside of the pit and is shown in Figure 155. The adapter booster is believed to have caused this reaction. Its thermogram is shown in Figure 156. The rapid temperature rise before ignition is indicative of a booster adapter reaction.

The short reaction times of the three of the four assemblies in Fuze Test No. 28 caused a great deal of concern. Three

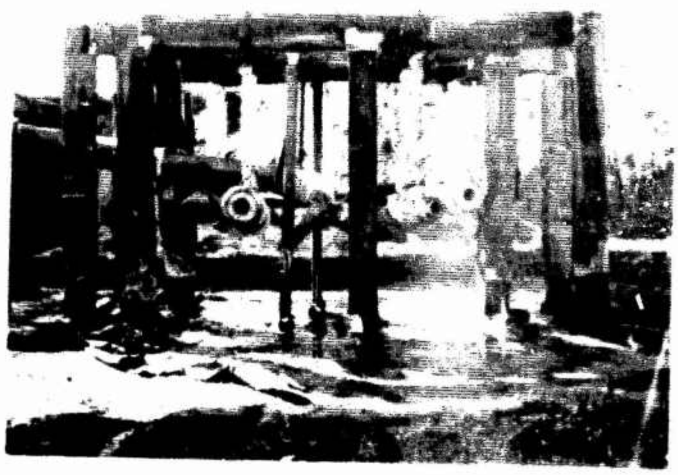


FIG. 150 PHOTOGRAPH OF PIT AFTER COOK-OFF TEST

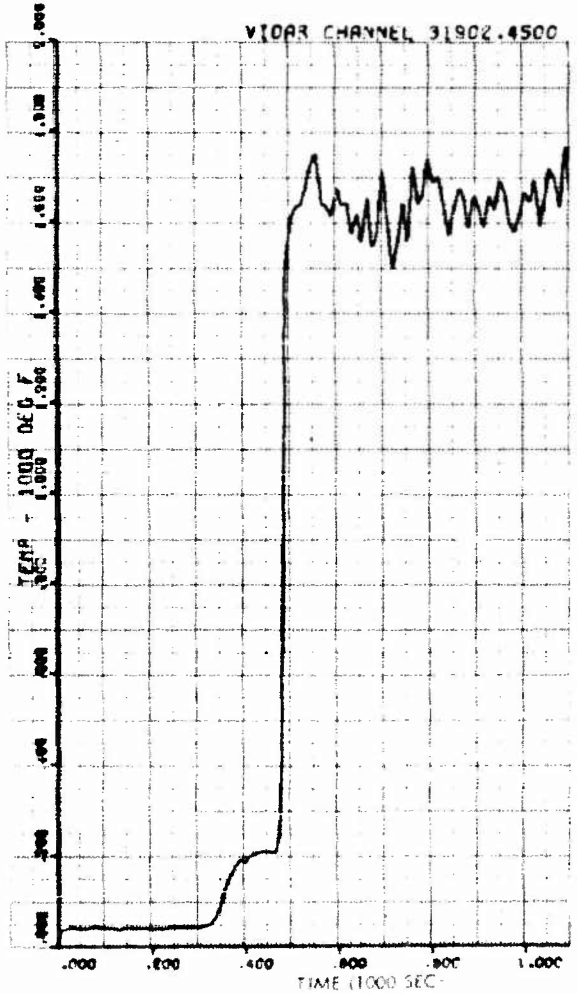


FIG. 151 FUZE TEST NO. 28 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 PROTECTED WITH CANDIDATE NO. 14 SLEEVE

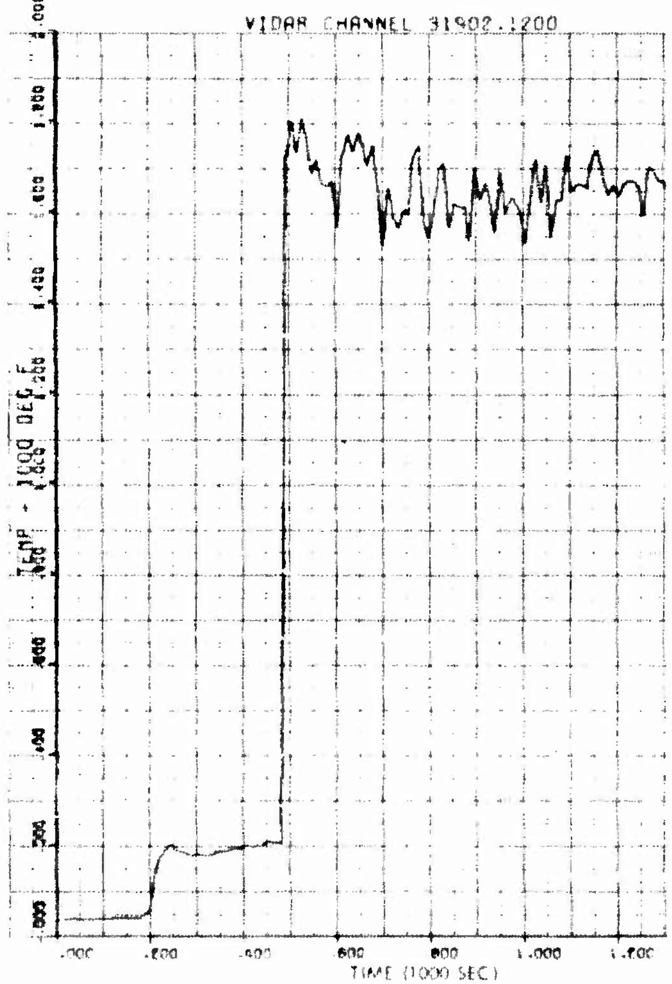


FIG. 152 FUZE TEST NO. 28 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 10 SLEEVE FROM A NEW SOURCE

FIG. [illegible] PHOTOGRAPH OF ABLATED CANDIDATE NO. 14 SLEEVE AFTER TEST

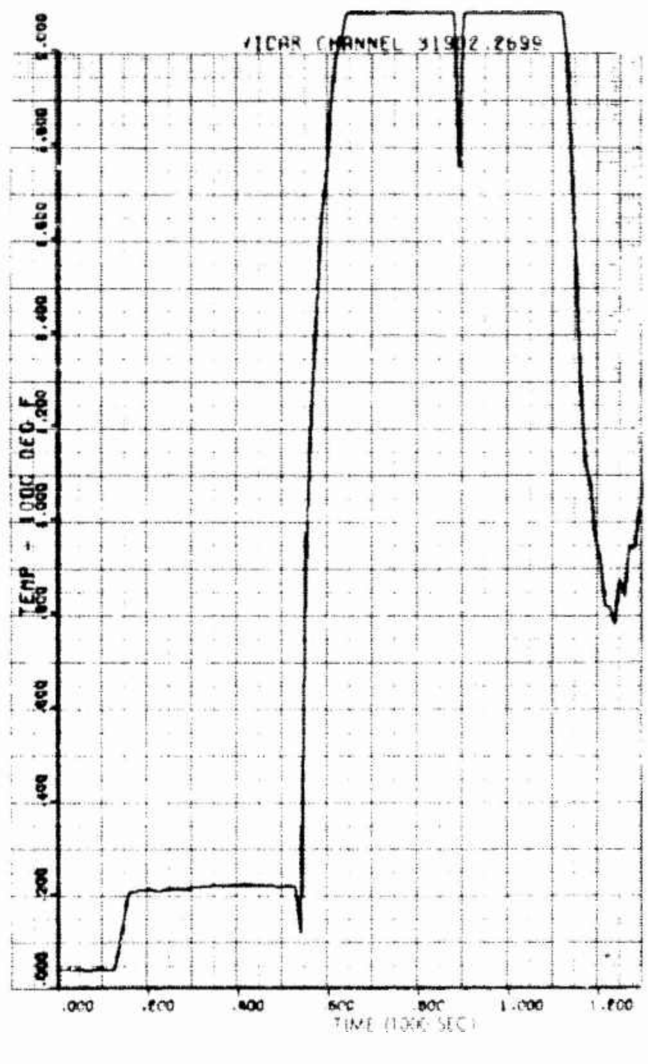


FIG. 154 FUZE TEST NO. 28 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 10 SLEEVE FROM A NEW SOURCE

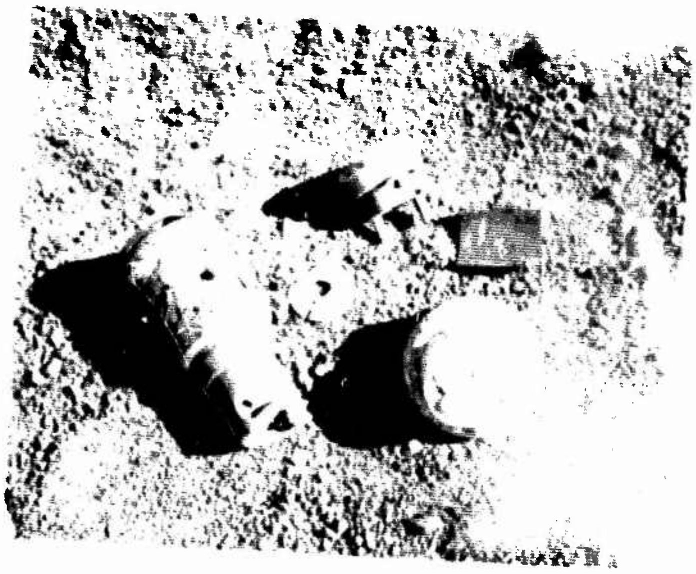


FIG. [illegible] FUZE

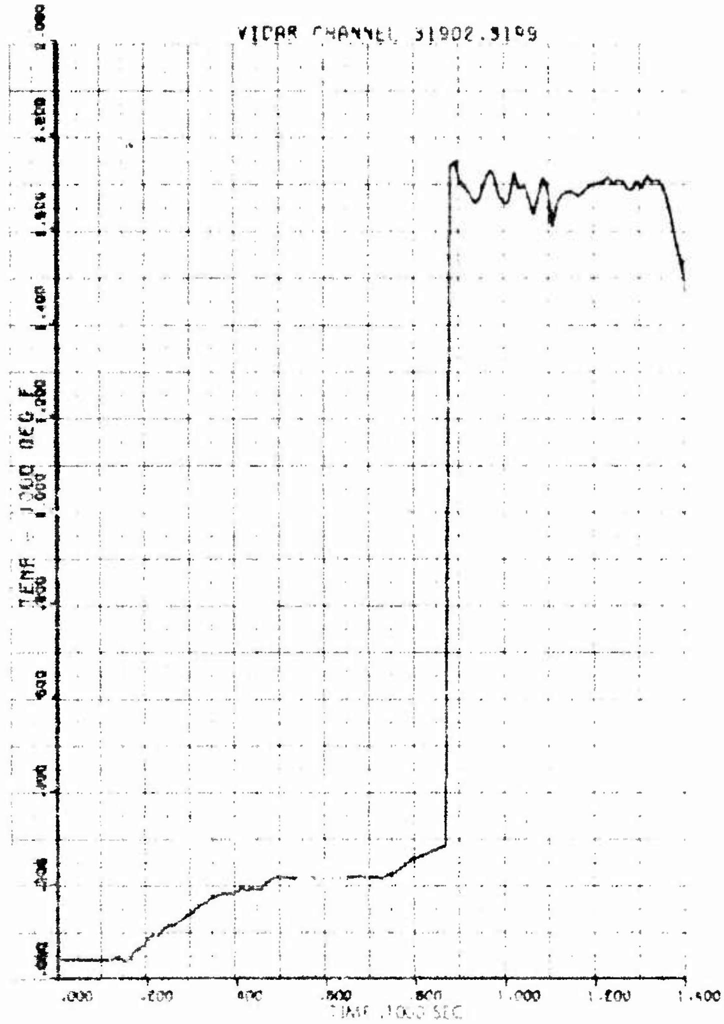


FIG. 156 FUZE TEST NO. 28 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING M904E2 FUZE PROTECTED WITH CANDIDATE NO. 10 SLEEVE

possibilities were postulated. The first possibility considered was that the protective sleeving contained occluded air which when heated caused the sleeves to fracture and fall off. This was rejected since the Candidate No. 14 fuze covering was still intact on the fuze body, yet reaction time was only 540 seconds. The second possibility considered was that the heat transfer through the three unprotected holes inserted in the fuze covering for the stop screw, upper observation window and setting index locking pin caused early reactions. Maximum heat transfer through these areas occurs when the openings are directed toward the fire. On a close review of the photograph taken before the test, the fuzes with the shorter cook-off time were orientated in this unfavorable position. These photographs are shown in Figures 157 and 158. It was confirmed that in the case of three assemblies the holes are oriented toward the rising fire. The third possibility was that the Insunol was not effective as an insulator in the closed adapter booster situation since it must intumesce before it performs an insulation function.

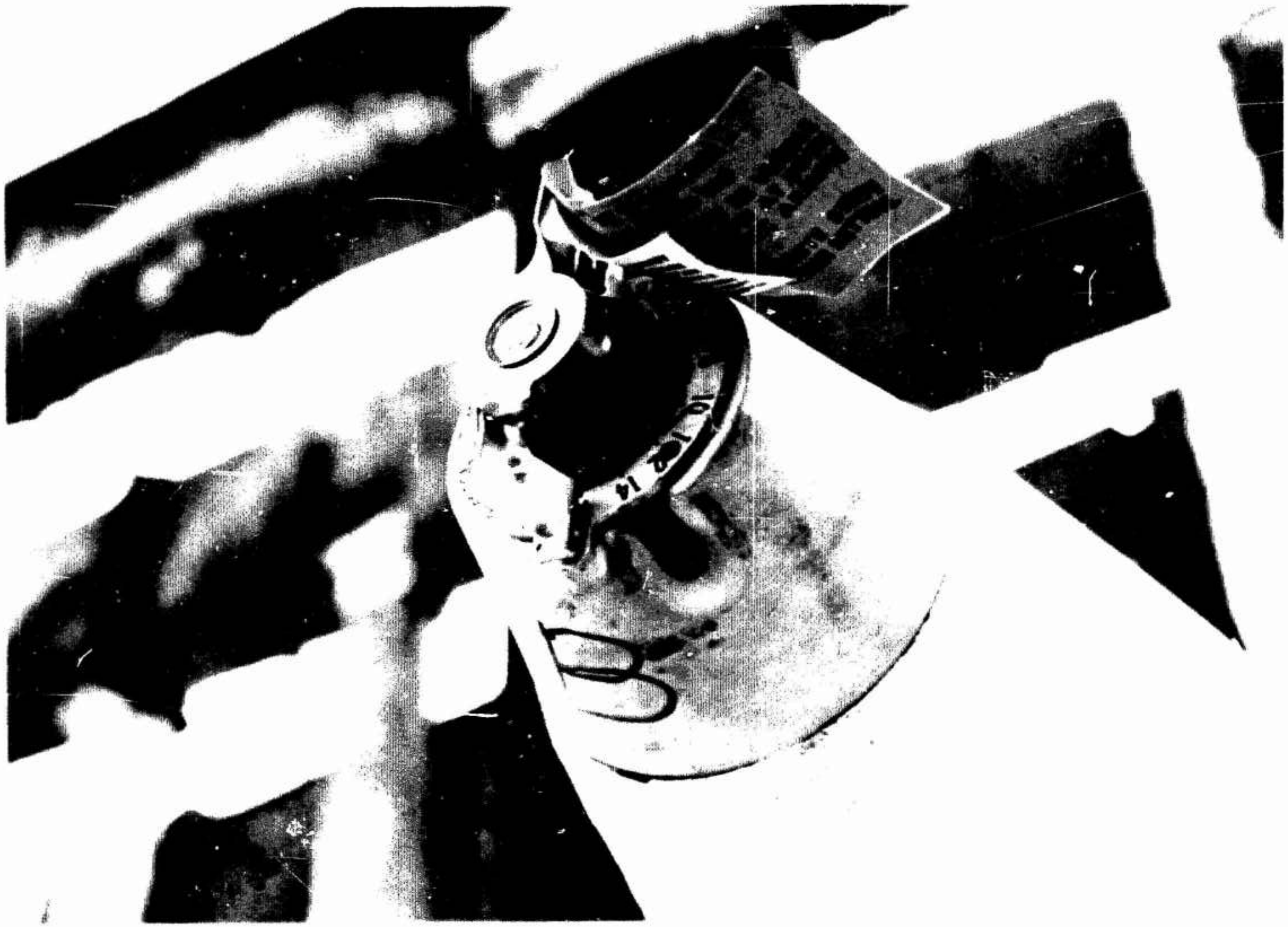
Fuze Test No. 29

The last experiment in this fuze series was designed to determine (1) whether orientation of the fuze influenced reaction times, and (2) whether the Candidate No. 10 material used as a disc and washer in the M148 Adapter Booster would be an improvement over Insunol.

Four thermally protected concrete loaded bombs were used as before. The same thermocouple arrangement was used as in the previous tests. All fuzes and adapter boosters were explosive loaded. The sleeves were bonded to the Nose Fuze M904E2 with RTV 3145. Instead of the intumescent paint, a disc and washer of Candidate No. 10 material .100" inches thick were used. These are shown in Figure 159. The aluminum sleeve was reduced in length to accommodate the added thickness of the disc and washer. The length was cut from a nominal length of 3.290 to a length of 2.906". All of the adapter ring faces of the adapter booster were coated with Insunol.

Two Fuzes M904E2 were protected with Candidate No. 10 sleeves. One fuze was oriented with the openings (holes and slots) toward the fire and the other away from the fire. The other two Fuzes M904E2 were protected with the Candidate No. 10 sleeves. One fuze was oriented with the openings toward the fire, the other oriented away from the fire. The wind velocity was higher than usual and was between 3-5 knots. The fire temperature was lower than in our previous tests, averaging approximately 1480°F (Figure 160).

The first reaction was experienced thirteen minutes forty seconds (820 seconds) after the start of the fire. The Fuze M904E2 protected with Candidate No. 14 sleeve with the openings oriented toward the fire detonated violently, destroying half the bomb. The


10
12
14

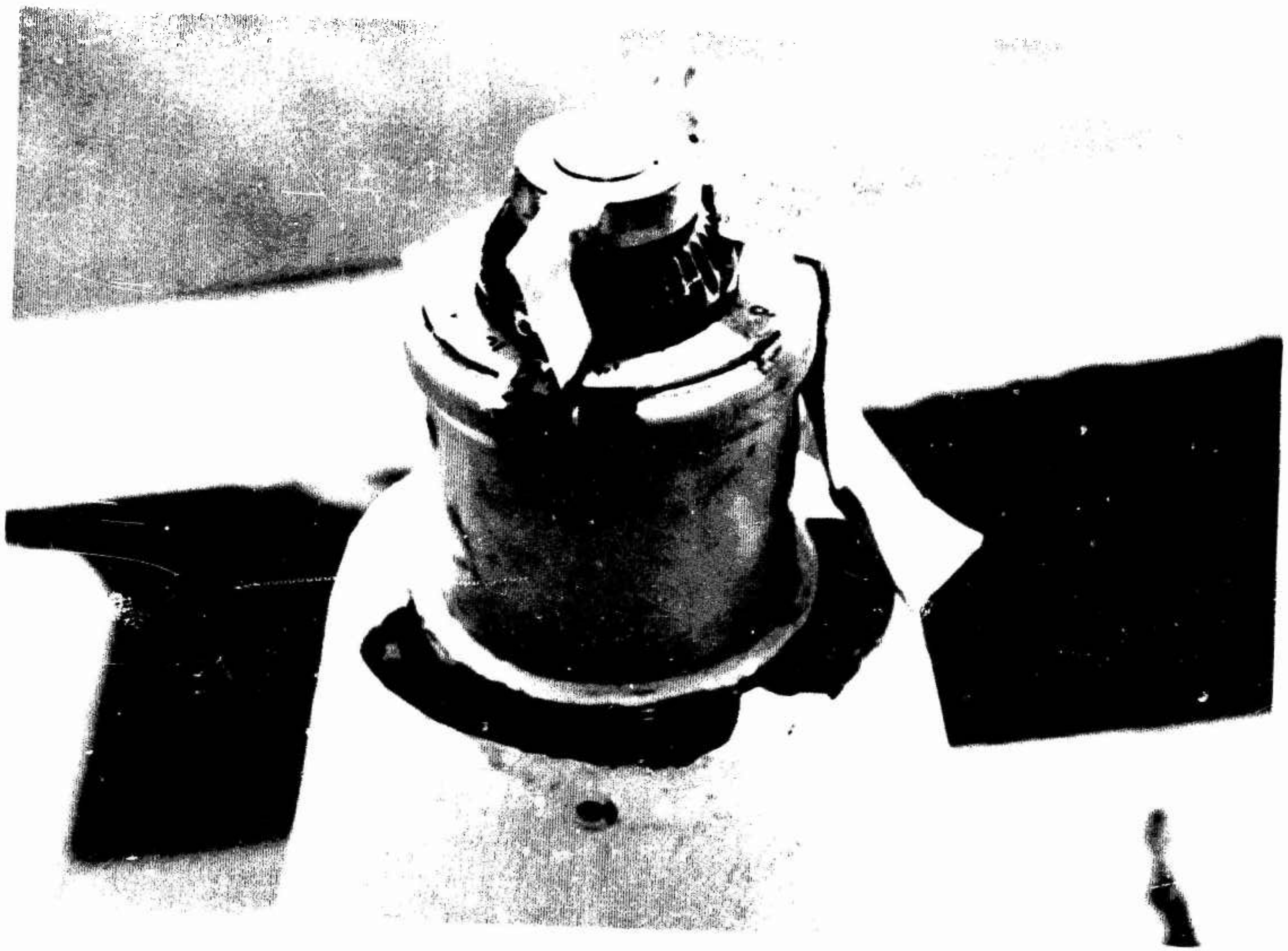


FIGURE 158. [illegible] TEST [illegible] PHOTOGRAPH OF CANDIDATE NO. 10 SLEEVE WITH SLOT ORIENTATED TOWARD FIRE

[illegible] GRAPHITE DISC AND [illegible] MATERIAL.

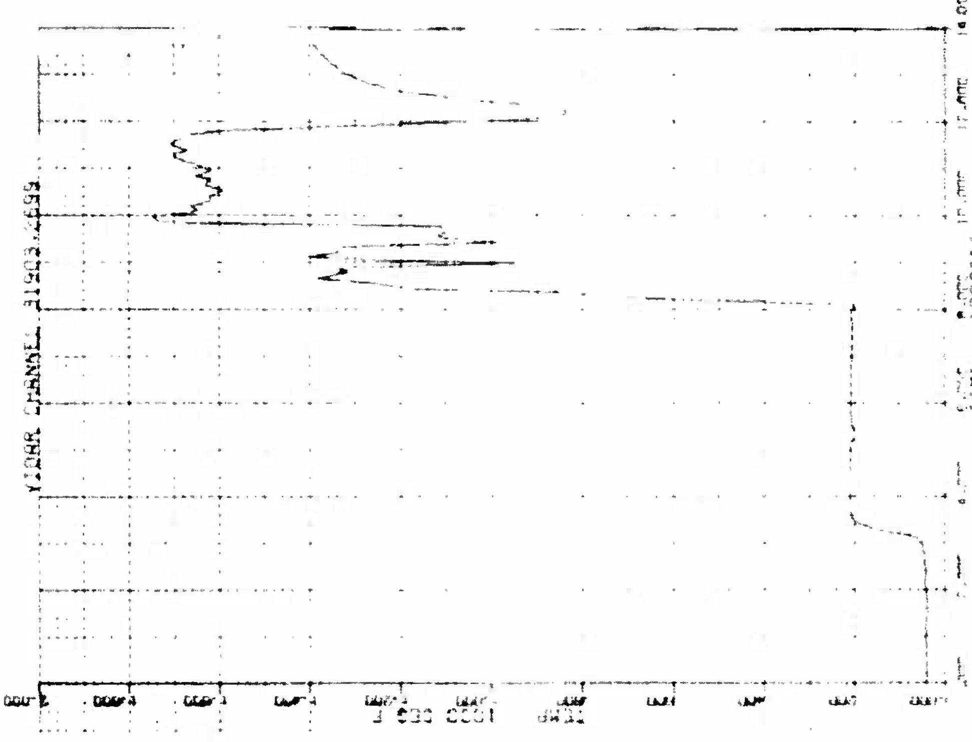


FIG. 161 FUZE TEST NO. 29 THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING FUZE M904E2 PROTECTED WITH CANDIDATE NO. 14 SLEEVE

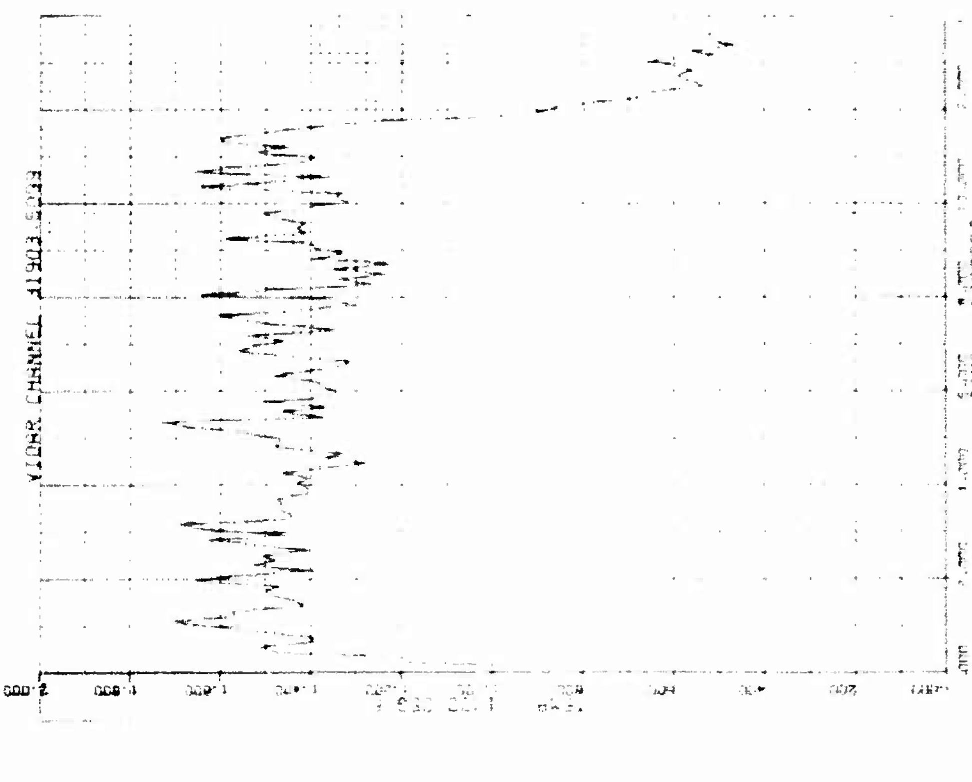


FIG. 160 FIRE TEST NO. 29 THERMOGRAM OF FIRE TEMPERATURE THERMOCOUPLE

reaction seemed to occur in the fuze, after examining the adapter booster thermocouple data. The time temperature plot of the thermocouple is shown in Figure 161.

The second reaction occurred in fourteen minutes fifty-five seconds (895) seconds) with the fuze protected with the candidate No. 10 sleeve. Again, the holes were orientated toward the fire, and again the bomb detonated. This resulted in banana peeling of the front of the bomb and is shown in Figure 162. The thermocouple plot is shown in Figure 163. The reaction again appears to have started in the fuze.

The third reaction occurred sixteen minutes (960 seconds) after the start of the fire. The Fuze M904E2 contained the candidate No. 10 sleeve with the holes orientated away from the fire. The reaction again resulted in a detonation, destroying the front end of the bomb. The reaction appears to have originated in the fuze. The adapter booster thermocouple trace is shown in Figure 164.

The last fuze containing the candidate No. 14 sleeve reacted in nineteen minutes forty seconds (1180 seconds). The adapter booster appeared to have started to self-heat, however, the fuze is believed to have caused the reaction due to the low exotherm produced. This is shown in Figure 165. The bomb detonated just as the fire was dying out. The fuze cover was oriented with the opening away from the fire.

These results of Fuze Tests 27, 28 and 29 are summarized in Table 22.

It appears that (1) the orientation of the holes and slots in the sleeve downward contribute to the rapidity of cook-off and (2) intumescent paint does not perform its insulation function in the closed adapter booster application.

SUMMARY AND CONCLUSIONS

The Mk 80 series of bombs are composed of three major elements that are vulnerable to cook-off namely (1) fuzes (2) adapter boosters and (3) the main charge. The work on extending the cook-off of the main charge has been carried out under another program. It was a desired goal that the fuze and booster cook-off time exceed the main charge.

(1) Cook-off tests on an unprotected Nose Fuze M904E2 in a thermally protected H-6 loaded Mk 82 Bomb (coated internally with 1/4" high temperature hot melt and externally with intumescent paint) cooked off in approximately five minutes. The Mk 346 Fuze cooked off in approximately eight minutes. A solution to the Mk 346 Fuze cook-off problem was not pursued. Fire tests indicated that when the flame was directed into an M148 open adapter booster cavity, assembled in a bomb, (assisted by at least a 10 knot wind) cook-off occurred in less than four minutes. Under calm conditions, time of 10 minutes or more were experienced.

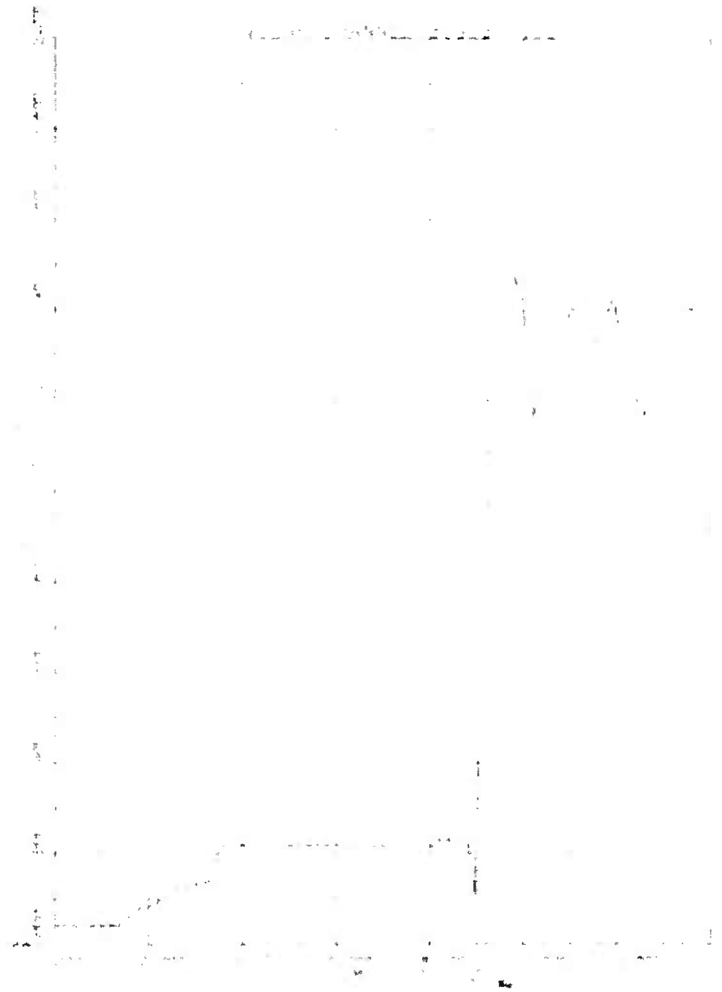


FIG. 142 TEST NO. [illegible] THERMOGRAM OF A M148 [illegible] ADAPTER BOOSTER CONTAINING [illegible] FUZE PROTECTED WITH CANDIDATE NO. 15 SLEEVE

FIG. 143 THERMOGRAM OF A LIVE ADAPTER BOOSTER - FUZE PROTECTED WITH CANDIDATE NO. 14 SLEEVE

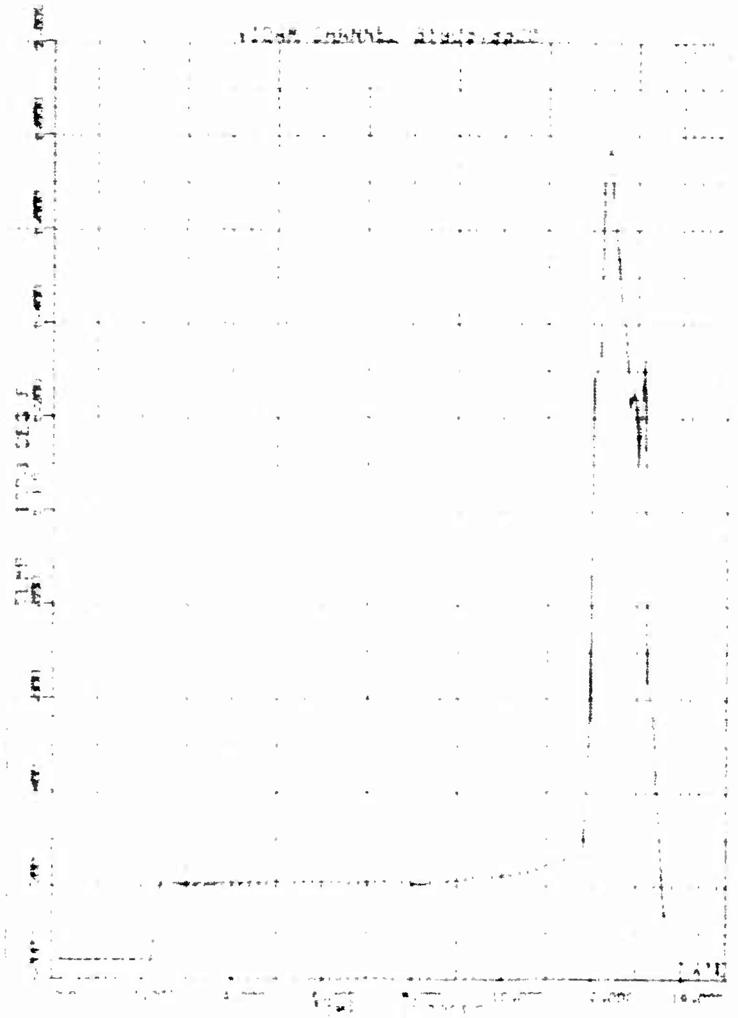


FIG. [illegible] FUZE TEST NO. [illegible] THERMOGRAM OF A LIVE M148 ADAPTER BOOSTER CONTAINING [illegible] PROTECTED WITH CANDIDATE NO. [illegible] SLEEVE

Table 22

Cook-Off Results of Nose Fuze M904E2 and Live M148 (T45E7) Adapter Booster - Combined Test Results

Fuze Test No.	Nose Fuze M904E2 Configuration	Adapter Booster Configuration	Reaction Time Sec.	Type of Reaction
27	Candidate No. 10 Sleeve and RTV 3145. Live Fuze.	Inert T45E7 and 34 mils Insunol on adapter ring, disc and aluminum sleeve.	1020	Deflagration
27	Candidate No. 10 Sleeve and RTV 3145. Inert Fuze.	Live T45E7 and 34 mils Insunol on adapter ring, disc and aluminum sleeve.	920	Deflagration
27	Candidate No. 14 Sleeve and RTV 3145. Live Fuze.	Same as above	475	Deflagration
27	Same as above	Same as above	950	Deflagration
28	Candidate No. 10 Sleeve and RTV 3145. Live Fuze.	Same as above	480	Deflagration
28	Same as above	Same as above	870	Deflagration
28	Candidate No. 14 Sleeve and RTV 3145. Live Fuze.	Same as above	475	Deflagration
28	Same as above	Same as above	540	Deflagration
29	Candidate No. 10 Sleeve and RTV 3145. Live Fuze. Slot directed toward fire.	Live T45E7 and 34 mils Insunol on adapter ring. Disc and washer of Candidate No. 10.	895*	Detonation
29	Same as above. Slot away from fire.	Same as above	1160*	Detonation
29	Candidate No. 14 Sleeve and RTV 3145. Live Fuze. Slot directed toward fire.	Same as above	820*	Detonation
29	Same as above. Slot away from fire.	Same as above	960*	Detonation

* Fire temperatures lower than in the other tests. The average fire fire temperature was 1480°F.

(2) Exploratory tests on possible approaches to extend fuze cook-off indicated that a sleeve of candidate No. 1 material, cemented to the exposed cylindrical portion of the Fuze M904E2, extended the cook-off time and this approach was pursued in developing a cook-off fix. A screening program was carried out involving some 15 candidates possessing physical properties ranging from thermoplastic material to rubber type materials. Some were eliminated based on poor thermal performance, others were eliminated because of poor performance under environmental treatment of temperature and humidity.

(3) A series of fire tests in the field reduced the fuze coverings to three, namely, candidates No. 1, No. 10 and No. 14. Candidate No. 1 (an elastic material) requires a high temperature adhesive for bonding to the fuze and it was dropped when the adhesive initially used was no longer available commercially, and no adequate replacement could be readily found.

(4) Candidate No. 14 required the greater thickness afforded by a truncated cone to provide acceptable cook-off time. The material was inexpensive enough to allow this increase in thickness. Under conditions of exposure to extreme temperature (-65°F to +160°F) severe cracking occurred and the greater diameter configuration reduced the number of fuzes that could be placed in each package from 12 to 9.

(5) Candidate No. 10 a filled butadiene-acrylonitrile polymer (military specification material) when fabricated into a sleeve 1/4" in thickness, and bonded to the Fuze M904E2 with RTV 3145, fulfilled every requirement. It produced outstanding char, had good environmental performance, and twelve fuzes could be packaged with this sleeve on the fuze.

(6) Candidate No. 14 and No. 10 sleeves were selected for final evaluation.

(7) A heat insulator on the face of the Adapter Ring of the Adapter Booster to interrupt the heat path was found necessary as a part of the Fuze M904E2 fix when the 1/4" thickness sleeve was used. Washers of candidate material No's 1 and 10 were tested and found satisfactory from a thermal protection point of view, however, they appeared impractical from a ship board handling standpoint. Intumescent paint gave comparable protection and was chosen as a fix as more acceptable on board ship than materials that would interfere with M148 Adapter Booster installation into bombs. An internal disc and washer of candidate No. 10 material was also included in the adapter booster. This combination was procured for evaluation.

(8) Cook-off times in excess of 1[illegible] minutes were obtained with the complete fix (M904E2 Fuze with candidate No. 10 sleeve, M148 Adapter Booster with intumescent paint on adapter ring and candidate No. 10 washer and disc internally), however, detonations were the final action. It was suspected that the candidate No. 10 material outgassed considerably at elevated temperature and together with

intumescense probably provided favorable conditions for confinement of the explosive and consequent violent reaction. A rigid phenolic material for the disc and washer would have been a better choice.

(9) Orientation of the fuze so that the holes and slots in the sleeve were directed downward caused shorter cook-off times than when the openings were up.

(10) Cost and time precluded a program of extensive testing and the establishment of statistical confidence in a minimum fuze cook-off time attained by the fixes, however, the limited results tests indicate that at least a 10 minute thermal protection was obtained for both the M904E2 Fuze - M148 Adapter Booster combination or the adapter booster without a fuze.

ACKNOWLEDGEMENT

The author wishes to thank Mr. David Dancer for his invaluable assistance in the data reduction and in the theoretical analysis of the data, and Mr. H. Cleaver for the design and fabrication of the pin switch circuit.

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2. Takata, A. N., et al, "Final Report of Fire and Impact Tests, Joint AEC-DOD Vulnerability Program", AFSWC TDR-62-132, DASA 1276, 1963 (SRD).

3. Bader, B. E., "Heat Transfer in Liquid Hydrocarbon Fuel Fires", SC DR 320-63, Sandia Corporation, February 1964.

4. NOL ltr 043:BL:sw 8010 Serial No. 4683 of 17 August 1971 to NMC, Point Mugu, California and NAVAIRSYSCOM.

APPENDIX A

U. S. NAVAL ORDNANCE LABORATORY
White Oak, Silver Spring, Maryland

233:HC:jej

1 July 1969

From: Harry Cleaver
To: NOL Files

Subj: Pin Switch Control Box

Abst: Pin Switch circuits are being used in the Bomb Cook-off program to establish the origin of any detonation wave in the event that detonation does occur. Operating instructions and a circuit description for the pin switch control box are contained in this note.

Encl: (1) Display of Probes Triggered in Order - Figure 1 and Pin Switch Circuit - Figure 2
(2) Pin Switch Circuits - Figure 3
(3) Pin Switch Control Box Schematic - Figure 4

OPERATING INSTRUCTIONS

1. Attach the multiconductor pin switch input cable to the side of the control box. A grounding switch is provided to short the input cable while personnel are setting up the test model at the burning pit site. This switch can be left on the grounded position at all times other than when the control box is to be operated. To put the box into operation, turn on the power switch and unground the input cable. The red READY light will then go on. Adjust the capacitor voltage to the level desired using controls in lower left hand section of top panel.

2. Test each pin switch circuit for external shorts. Test one circuit at a time using the 12 position (10 probes and 2 off) selector switch and the pushbutton TEST switch.

A. Set up the oscilloscope controls for

+ INTERNAL DC TRIGGERING

5 VOLTS/CM vertical sensitivity*

50 MICROSECONDS/CM sweep time*

B. Use either a differential preamplifier operated in the A-B DC mode or a dual trace preamplifier operated channel A normal, channel B inverted, in the ADDED ALGEBRAICALLY mode.

* or as dictated by voltage level and probe placement.

Subj: Pin Switch Control Box

C. Connect points marked CHAN A and CHAN B to the A and B inputs to the oscilloscope.

D. Set selector switch to probe 1 position and, adjusting the oscilloscope trigger level and stability, test for a signal from pin switch number one. Refer to Figure 1 for the signal to be expected from any given probe.

E. Test odd numbered pin switch probes 1, 3, 5, 7, 9 adjusting oscilloscope triggering as needed.

F. Change the oscilloscope internal triggering from POSITIVE to NEGATIVE to test for the even numbered probes.

G. Adjust the trigger level and stability for negative triggering and check probes 2, 4, 6, 8, 10.

H. Absence of a test signal for any probe circuit indicates a shorted probe. Since a test signal can be generated whether the pin switch probes are connected or not, breaks in the input cable cannot be detected. There is no easy way to check for open circuit continuity.

I. Since I know nothing about the tape recorder to be used with this control box, no mention will be made of its checkout or operation. Ten separate output connectors are provided for use with the tape recorder. All the signals going to the tape recorder are negative in polarity and of the same amplitude which is equal to the signal from probe No. 1.

3. When all the probes have been checked out and the system is ready, the final oscilloscope control settings are to be as in 2A above. The triggering level and stability should be set so that a test signal of the lowest positive amplitude (signal from probe No. 5) will trigger the sweep. This means that the oscilloscope will trigger upon the first pulse generated by any odd numbered probe.

THEORY

1. Figure 2 shows the basic pin switch circuit. The capacitor C is charged through a relatively high resistance R_1 and R_s to the potential of the supply voltage. Since $R_s << R_1$, R_s can be neglected in discussing the capacitor charging operation. When the pin switch is closed, the capacitor discharges through R_s generating a single pulse. The charging time constant R_1C is made much larger than the discharge time constant R_sC to avoid any regeneration of the signal during the experimental time interval.

The line resistance R_L represents the total resistance in the connecting wires leading to the pin switch. In most cases this

Subj: Pin Switch Control Box

resistance is negligible but in the present situation it is not. There is at least 1000 feet of No. 22 AWG copper wire leading to the test site with an additional length of about 60 feet of type K thermocouple wire added on the end. Taking a value of 16 ohms per 1000 feet for the copper wire and 2.4 ohms per combined foot for the thermocouple wire we have a line resistance of nearly 180 ohms. This resistance must be used in computing the RC discharge time constant. Being in series with the discharge path resistor R_s, the line resistance acts to reduce the signal amplitude seen by the recording instruments by virtue of its voltage drop.

In practice a number of identic. pin switch circuits are used in a given experiment. The pin switches are physically displaced at a known separation in the test object. Closing of the pin switches by the event under study generates a pulse pattern which is studied for time displacement between signals.

2. Figure 3 is a partial schematic of the circuits used to produce the display shown in Figure 1. The purpose of such a display is to provide each individual probe with its own identifiable signal characteristics. The pulses as shown vary in amplitude, polarity, and width. There are 10 circuits divided into groups of 5 each. The odd numbered circuits go to oscilloscope channel B while the even numbered circuits go to channel A. All pulses generated by the circuits have negative polarity. Signals to the oscilloscope B channel are inverted by the A - B operation and appear as positive in the display. Signals to channel A are not inverted and appear negative in the display. Amplitude variation is achieved by holding the total discharge path resistance constant at 51 ohms but picking off the output signal through various resistor divider networks at approximately full signal, 2/3, and 1/3 full signal. Pulse width variation is achieved by using different capacitor values to change the RC discharge time constant.

The charging time constant for the first six probe circuits is 2.2M ohms x .05 mfd or 110 milliseconds. Discharge time constant, assuming 180 ohms for R_L, is 230 ohms x .05 mfd or 11.5 microseconds. The remaining four circuits have a .1 mfd capacitor which doubles their time constant to 220 milliseconds for charging and 23 microseconds for discharging.

The diodes shown in Figure 3 are used to isolate the circuits from each other. The resistor connected to the signal output terminal is used to provide a comparable time constant on the anode side of the diode string. The tape recorder connections are made at the capacitor-resistor junction so that the full signal voltage is sent to the tape recorder. Each signal to the tape recorder is recorded on a separate track so unique characteristics are not needed for identification.

Subj: Pin Switch Control Box

3. Figure 4 is the complete schematic for the control box showing all ten pin switch circuits. Two parts not discussed so far are the power supply and the test circuit sections.

The power supply transformer applies stepped down full wave rectified voltage to a resistor-capacitor filter. An output voltage of 36 volts DC is developed across the 100K ohm adjustment pot. Power, ripple, and regulation requirements are minimum for this application and aided the simple design.

A silicon controlled rectifier (SCR) is used in the test section to simulate the pin switch. The SCR is connected to any desired pin switch circuit using the 12 position selector switch such that the SCR is in parallel with the pin switch probe. A 150 ohm resistor is used in series with the SCR to represent the line resistance. The test signal generated will then appear similar to the true signal. The SCR is triggered by a pulse from the 0.1 mfd capacitor discharging through the 51 ohm gate lead resistor when the test button is actuated. The 100K and 13K ohm divider holds the voltage on the capacitor to just over 4 volts. This type of capacitor discharge triggering was used because of the low current output capabilities of the power supply section.

HARRY E. CLEAVER
Chemical Engineering Division

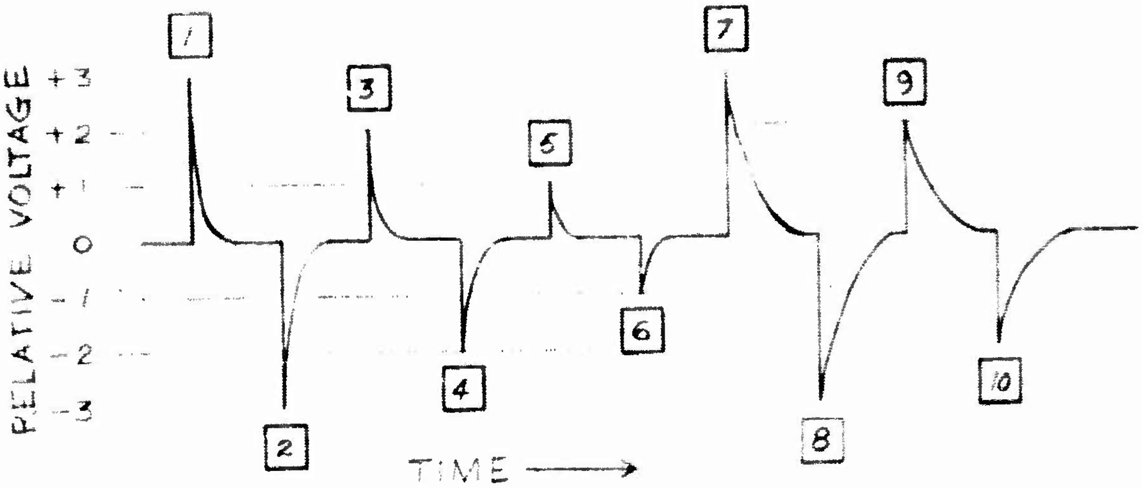


FIG 1. DISPLAY OF PROBES TRIGGERED IN ORDER

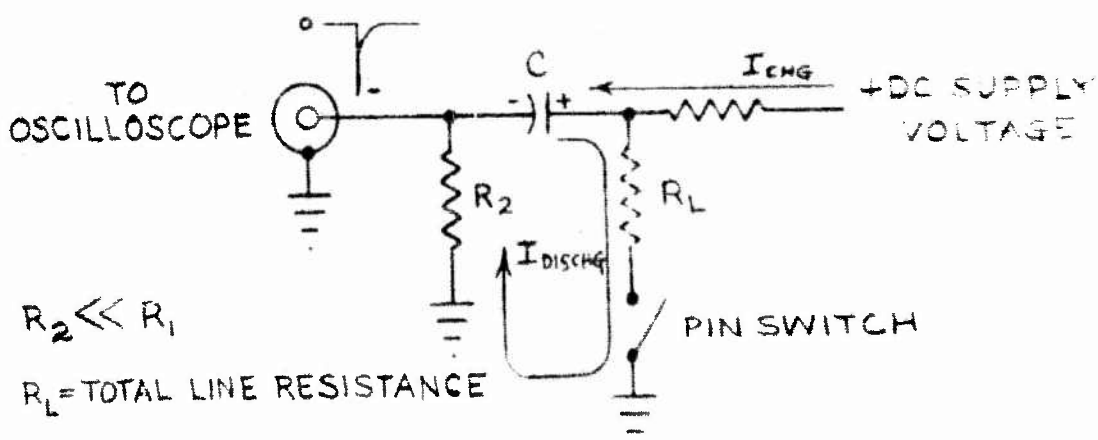
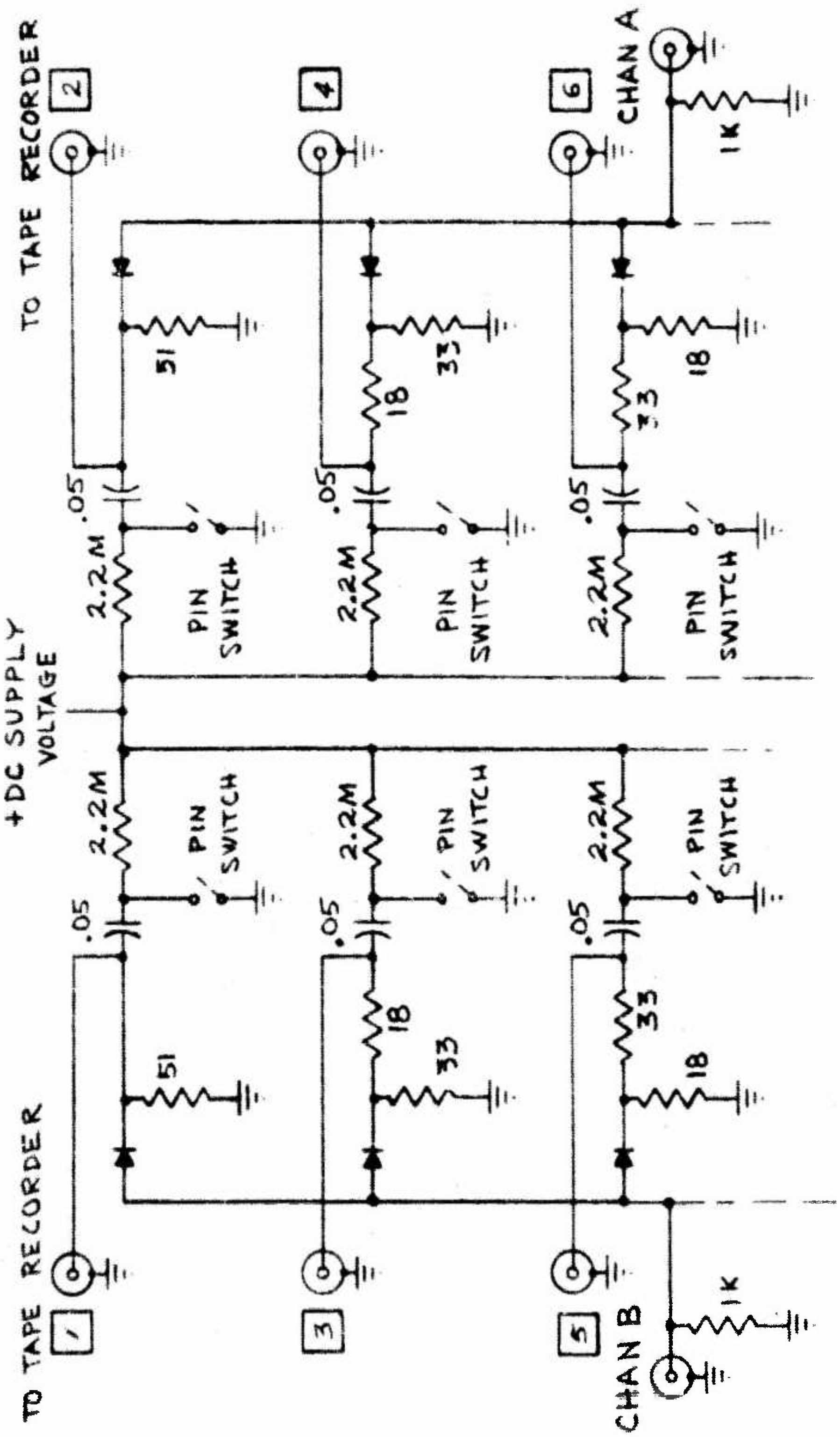


FIG 2. PIN SWITCH CIRCUIT

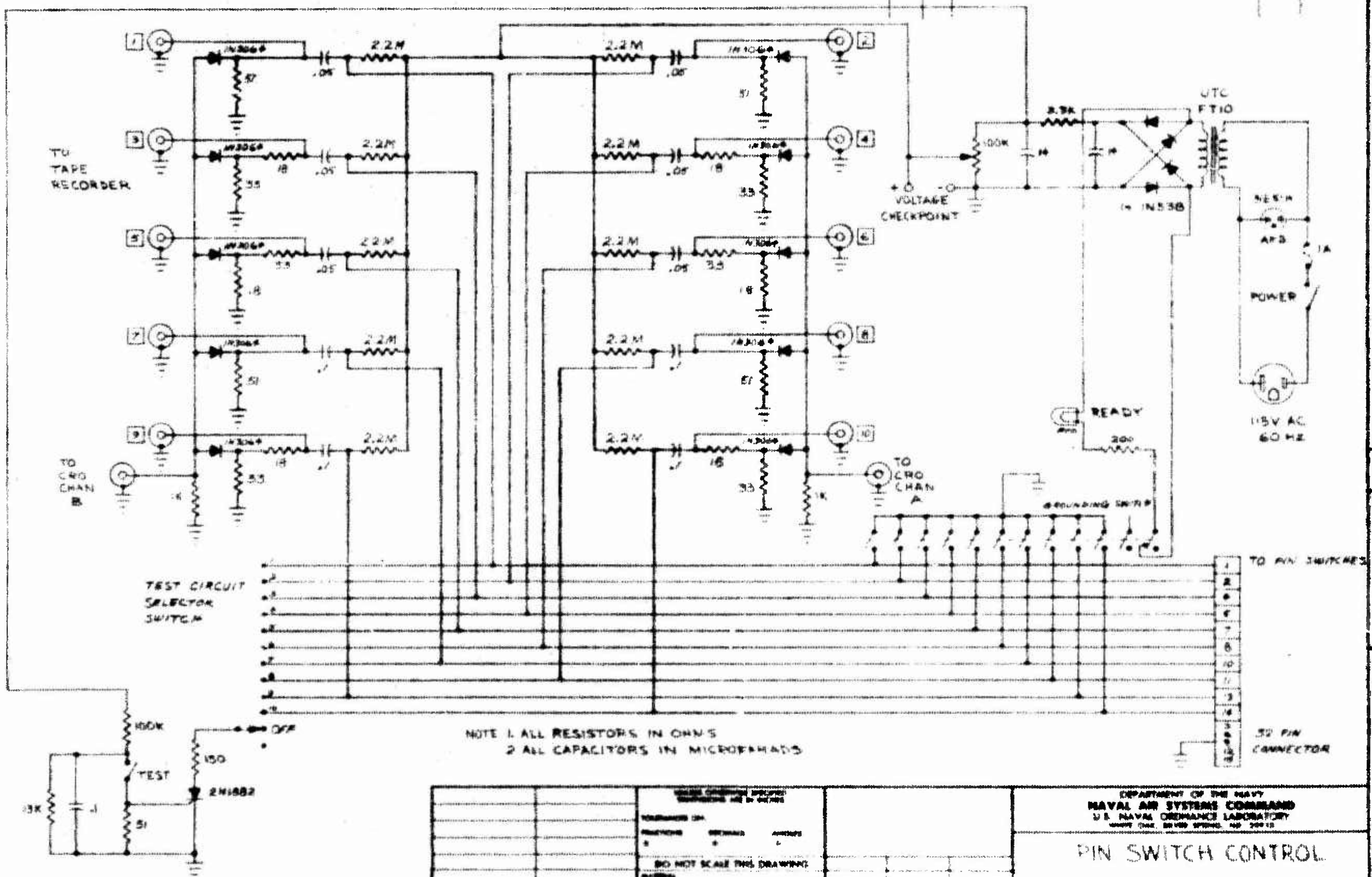


ALL DIODES ARE 1N3064.
RESISTORS IN OHMS, CAPACITORS IN MFD.

FIG 3. PIN SWITCH CIRCUITS

Enclosure (2)

NOLTR 71-124



NOTE 1. ALL RESISTORS IN OHMS
2 ALL CAPACITORS IN MICROFARADS

DO NOT SCALE THIS DRAWING

APPLICATION

DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
U.S. NAVAL ORDNANCE LABORATORY

PIN SWITCH CONTROL

FIG 4

C 30003

Enclosure (3)

APPENDIX B

```
[illegible]TAC,T900,CM1[illegible],52300593,126,[illegible].
ATTACH(ABC,NOLBIN)
COPYN(0,DFF,ABC)
RETURN(ABC)
FTN(L)
LOAD(LGO)
REQUEST,TAPE3,HI,S.(LEVINE6/NORING)
REQUEST,TAPE99,LO.(CALCOMP/RING)
DFF.
.
REWIND(ABC)
CALCH1,13,ABC
SMOOTH,2,ABC
.
      PROGRAM [illegible]TAC(INPUT,OUTPUT,TAPE5=INPUT,[illegible],
     1 TAPE3,          TAPE7,TAPE8,TAPE99)
      DIMENSION ITICH(50),ISCH(50),X[illegible](50),I[illegible](50),I[illegible](50),
     2 T[illegible]ATA(200),TIDATA(200),[illegible]ATA(50),XXDATA(200,50),[illegible](50)
     3 ,ILTCH(50),SMTEMP(200),                                 ISMOOT(50)
      DATA A,B,C/ -.6598,.02[illegible],[illegible]/
      DATA D,E/ 1.86,3.72/
      DATA ISIC1,ISIC2/ 1H+,1H-/
    4 FORMAT (A1)
      READ (5,5) NPROB
      WRITE (6,5) NPROB
      DO 999 L = 1,NPROB
      NDATP = 0
      J = 0
      ICY1 = 0
      ICY = 1
      IFLAG = 0
      DO 103  I = 1,50
  103 XDATA(I) = 0.
      DO 203 I = 1,50
      DO 203 J = 1,200
  203 XXDATA(J,I) = 0.
      READ (5,3) TIMINC,TIMST,TEM1,TEM2
      WRITE(6,3) TIMINC,TIMST,TEM1,TEM2
    3 FORMAT (8F10.3)
      READ(5,5) NCH,NSHOT,NSKIPF,          N,NPTICH,IREW,IPLOT,          IVID
     2 ,NSKIPD
      ANCH = NCH
      WRITE(6,5) NCH,NSHOT,NSKIPF,          N,NLTICH,IREW,IPLOT,          IVID
     2 ,NSKIPD
      READ(5,5) NTICH,(ITICH(I),I =1,NTICH)
      WRITE(6,5) NTICH,(ITICH(I),I =1,NTICH)
      READ(5,5) NSCH,(ISCH(I),I =1,NSCH)
      WRITE(6,5) NSCH,(ISCH(I),I =1,NSCH)
      READ(5,5) NLTCH, (ILTCH(I), I=1,NLTCH)
      WRITE(6,5) NLTCH, (ILTCH(I), I=1,NLTCH)
      READ (5,555) (ISMOOT(J) ,J=1,NCH)
      WRITE(6,555) (ISMOOT(J) ,J=1,NCH)
```

```
  555 FORMAT(80I1)
    5 FORMAT (16I5)
      ANSHOT = NSHOT
      IF(NSKIPF.EQ. 0) GO TO 996
C SKIP FILES
C PROGRAM COMES HERE IF YOU READ IN A VALUE OF NSKIPF .GT. 0
C                              OR IF PROGRAM FINDS THAT VI OR CHANNELS ARE OUT OF
C PROPER ORDER OR IF THE SIGN OF NBTICH IS NOT + NOR -
  890 CONTINUE
C THE FOLLOWING PROCEDURE TO SKIP A FILE WILL NOT WORK IF THE NO OF RECORDS
C ON THE FILE EXCEEDS 10000
      DO 995 J = 1,NSKIPF
      DO 994  I = 1,10000
      READ (N,4) IDUM
      IF (EOF(N)) 995,994
  994 CONTINUE
  995 CONTINUE
      IF (IFLAG) 30,996,30
  996 CONTINUE
      ICY = 0
      WRITE(6,1)
    1 FORMAT(1H1)
    2 CONTINUE
      READ(N,10) (IDATA(I),ISIGN(I),JDATA(I),IEXPO(I), I =1,10)
   10 FORMAT(10(I3,A1,I6,I1,1X))
      IF (EOF(N)) 30,11
   11 CONTINUE
      IF (IOCHEC(N)) 30,9011
 9011 CONTINUE
      IF (NBTICH .LT. 0) GO TO 210
      NBTJ = NBTICH - IVID
      ISIG3 = ISIGN(NBTJ)
      IF (ISIG3 .EQ. ISIG1 .OR. ISIG3 .EQ. ISIG2) GO TO 210
      WRITE(6,10) (IDATA(M),ISIGN(M),JDATA(M),IEXPO(M), M =1,10)
      WRITE(6,110)
  110 FORMAT(119H FOR THIS CYCLE, THE SIGN OF NBTICH IS NEITHER + NOR -.
     2 PROGRAM IGNORES DATA FROM THIS CYCLE AND ALL SUCCEEDING CYCLES.)
      NSKIPF = 1
      IFLAG = 1
      GO TO 890
  210 CONTINUE
      DO 15 I = 1,10
      NDATP = NDATP + 1
      IF (NDATP .LE. NSKIPD)  GO TO 15
      J = J + 1
      IF (J .LE. NCH)      GO TO 1015
C START A NEW CYCLE
      ICY = ICY + 1
      J = 1
 1015 CONTINUE
      JVID = J + IVID
      IF (IDATA(I) - JVID) 310,510,310
  310 WRITE(6,10) (IDATA(M),ISIGN(M),JDATA(M),IEXPO(M), M =1,10)
      WRITE(6,410)
  410 FORMAT(119H FOR THIS CYCLE, THE CHANNELS ARE NOT IN PROPER ORDER.
     2 PROGRAM IGNORES DATA FROM THIS CYCLE AND ALL SUCCEEDING CYCLES.)
      NSKIPF = 1
```

```
      IFLAG = 1
      GO TO 890
  510 CONTINUE
   20 FORMAT(  /10(1X,I4,F8.1)/)
      XDAT = JDATA(I)
      IEXP = IEXPO(I) - 3
      XXDATA(ICY,J) = XDAT/10.**IEXP
C A CYCLE HAS BEEN COMPLETED
      IF (J .EQ. NCH) ICY1 = ICY1 + 1
   15 CONTINUE
      IF(L .NE. 2 .OR. NDATP .LE.6000) GO TO 2
   30 CONTINUE
      ICY = ICY1
      IF (ICY .LE. 0) GO TO 610
      DO 600 J = 1,NCH
      AJ1 = J - 1
      JVID = J + IVID
      DO 9 I =1,NSCH
      IF (JVID.EQ. ISCH(I)) GO TO 600
    9 CONTINUE
      AJ = J + IVID
      PN = ANSHOT + AJ/100.
      DO 590 I = 1,NTICH
      IF (JVID .EQ. ITICH(I)) GO TO 600
  590 CONTINUE
      DO 595 I =1,NSCH
      IF (JVID.EQ. ISCH(I)) GO TO 600
  595 CONTINUE
      AJ= J - NBTJ
      TIMIN1 = AJ* TIMINC
      DO 597 M = 1,ICY
      UTIL = A - ABS(XXDATA(M,J))
      UTIL1 = B * B - 4. * UTIL * C
      TEDATA(M)=((SQRT(UTIL1) -B) / (2. *C))/ 1000.
      IF (NBTICH .LT. 0) GO TO 4987
      TIDATA(M) =(XXDATA(M,NBTJ)    + TIMIN1) / 100.
      GO TO 5987
 4987 AM1 = M - 1
      TIDATA(M) =(TIMINC * (ANCH*AM1 +AJ1) + TIMST)/ 100.
 5987 CONTINUE
  597 CONTINUE
 6987 FORMAT(28H UNSMOOTHED DATA FOR CHANNEL,I5,/
     1 8X,                                          112H TIME( 100SEC)
     2  TEMP(1000F)            TIME( 100SEC)          TEMP(1000F)            TIME
     3( 100SEC)          TEMP(1000F))
 7987 FORMAT(6F20.4)
      WRITE(6,6987) JVID
      WRITE(6,7987) (TIDATA(M),TEDATA(M),M=1,ICY)
      IF (IPLOT .LE. 0) GO TO 610
      TEMMX = TEM1
      DO 598 I = 1,NLTCH
      IF (JVID .NE. ILTCH(I)) GO TO 598
      TEMMX = TEM2
      GO TO 599
  598 CONTINUE
  599 CONTINUE
      IF (IPLOT .GT. 2) GO TO 602
```

```
      IF (ISMOOT(J) .GT. 1) GO TO 602
      CALL CALCM1(ICY, TIDATA,TEDATA,0,0.,15.,  0.,TEMMX,7.5,10.,
     2 13HVIDAR CHANNEL,13, 14HTIME -  100SEC,14,17HTEMP - 1000 DEG F,
     3 17,PN,18)
  602 CONTINUE
      IF (ISMOOT(J) .LE. 0) GO TO 600
      CALL SMOOTH (TEDATA,SMTEMP,2,5,ICY)
 8987 FORMAT(28H   SMOOTHED DATA FOR CHANNEL,I5,/
     1  8X,                                      112H TIME( 100SEC)
     2  TEMP(1000F)          TIME( 100SEC)       TEMP(1000F)          TIME
     3( 100SEC)       TEMP(1000F))
      WRITE(6,8987) JVID
      WRITE(6,7987) (TIDATA(M),SMTEMP(M),M=1,ICY)
      IF (IPLOT - 2) 600,603,603
  603 CONTINUE
      PN = -PN
      CALL CALCM1(ICY, TIDATA,SMTEMP,0,0.,15.,  0.,TEMMX,7.5,10.,
     2 13HVIDAR CHANNEL,13, 14HTIME -  100SEC,14,17HTEMP - 1000 DEG F,
     3 17,PN,18)
  600 CONTINUE
  610 CONTINUE
      IF (IREW .GT. 0) REWIND N
  999 CONTINUE
      CALL CALCM1(0,0.)
      STOP
      END
```

NOT REPRODUCIBLE

APPENDIX C

FAST COOK-OFF TEST SPECIFICATION FOR MARK 80 SERIES LD BOMBS*

1. Fast Cook-Off Test Arrangement

Test Pan Size - Minimum test pan size for MARK 80 series LD bombs is 24' square. Maximum pan size is 35' square.

Test Pan Construction - The test pan may be constructed on either a semi-permanent basis with steel plate, or, if it is expected to be destroyed by the ordnance being tested, it may be constructed in a cheaper manner from earth and polyethylene.

Providing a Level Surface for the Flame - Water should be used to fill the bottom of the pan to provide a level surface for the fuel.

Fuel Specifications - Fuel to be used should be JP-5 aircraft fuel when available, or JP-4 aircraft fuel as an alternate. The quantity of fuel should be sufficient to cause a reaction of the ordnance, or to insure a 15-minute fire, whichever is shorter (1500 gallons in the 24' pan will last approximately 15 minutes).

Fuel Ignition - For ignition of the aircraft fuel 20 gallons of gasoline and/or one gallon of ether should be added after the fuel is poured, when using JP-5. A suitable flame producing device should be used to initiate the fire, such as a thermite grenade, squib and powder bag, etc., and these should be in at least four locations so as to initiate burning over the entire fuel surface as rapidly as possible. Flame buildup time to 1000°F should not exceed 35 seconds.

Weather Conditions - For an unshielded 24' pan, a wind of three knots or less measured within 1000 feet of the test site at the level of the test item(s) is acceptable. For the 35' pan, a five knot wind or less measured within 1000 feet of the test site at the level of the test item(s) is acceptable.

Average Flame Temperature - An average flame temperature of 1650°F or greater at the weapon will be considered a good test. This average temperature is arrived at by averaging flame temperature from the time the flame reaches 1000°F or, in the case of live ordnance, until there is a reaction.

*THIS SPECIFICATION IS PRELIMINARY AND IS INTENDED FOR USE BY NWL/DAHLGREN, NWC/CHINA LAKE, NOL/WHITE OAK, NAD/CRANE, AND NMC/PT MUGU ONLY.

2. Test Item(s) Placement

Height of Test Item(s) (Live and/or Inert) Above Fuel - The lowest item(s) should be suspended with the centerline between 36" and 66" above the fuel surface.

Attitude - The test item(s) should be suspended with the centerline parallel to the fuel surface.

Suspension of the Test Item(s) - The test item(s) should be suspended above the center of the pan by the lugs used to hang it on the aircraft.

Test Item(s) Configuration - The following configurations are to be used:

a. All-up round; i.e., including operational fuzes and fin assembly.

b. Inert fuzes and no fin assembly.

c. Additional operational configurations as required.

3. Instrumentation

Thermocouples - Iron-constantan or chromel-alumel thermocouples shall be used to instrument the test item(s) internally and chromel-alumel thermocouples shall be employed externally.

Thermocouple Locations - External thermocouples shall be located in a horizontal plane coincident with the centerline of the test item(s). A minumum of four thermocouples should be used, spaced equally around the test item(s), one at each end and one at each side, one to six inches from the test item(s).

Suggested Thermocouple Records - Sampling and/or continuous temperature recorders will be used. When using sampling recorders no more than four seconds shall elapse between cycles; that is, from TC 1 through all TC's back to TC 1.

Camera Coverage - Color motion picture cameras will cover each test from at least two directions 90° apart. Both normal (24 fps) and high frame rate (48 - 200 fps) cameras may be used to provide complete coverage. Still cameras and/or motion picture cameras will be used for documentary purposes.

Time Records - Complete time-to-event histories of each test will be kept. This record may be obtained from thermocouple records in some cases, depending on the methods of recording. Ignition of the fuel will serve as Zero time in all cases. The time when the fire temperature first exceeds 1000°F (as measured by one or more of the external thermocouples) is used as the point at which the test item

is considered engulfed in flame. This time will be 35 seconds or less.

Pressure Measurements - In tests of live ordnance, pressure measurements should be taken to aid in determining the severity of any explosive reaction(s) which occurs.

REV	DESCRIPTION	DATE	APPROVAL
A6	SEE RDN 599AS105-A	10-8-71	KRT
B3	SEE RDN 599AS105-B	10-13-71	KRT

1.A. PRIMING COAT:
WASH PRIMER, MIL-C-15328 (0.3 TO 0.5 MIL THICK) AIR DRY 1 HR MIN.
RED IRON OXIDE PRIMER, TT-P-664 (0.8 TO 1.2 MIL THICK) AIR DRY 16 HRS MIN.

B. INTUMESCENT COATING MIXTURE: (30 MIL MIN. THICK) SEE NOTE 4

INGREDIENTS	%	
PARLON (CHLORINATED NATURAL RUBBER)	1.25% ± 10%	NOT TO EXCEED 6.45% TO 7.50%
PLIOLITE VT (SOLID VINYL-TOLUENE/BUTADIENE RESIN)	5.73% ± 10%	
MELAMINE	14.50% ± .50%	
TRIPENTAERYTHRITOL	9.20% ± .2%	
AMMONIUM POLYPHOSPHATE (90% PHOSPHATE CONTENT) "PHOSCHEK P-30"	29.71% ± 1.0%	
CHLORINATED PARAFFIN (70% CHLORINE) "CHLOROWAX"	3.36% ± .3%	
TOLUENE	15.0% NOM. TO SUIT APPLICATION METHOD	
XYLENE	15.0% NOM. TO SUIT APPLICATION METHOD	
"BENTONE 38" MONTMORILLONITE	0.40% ± .2%	
TiO_2	5.40% + 1.0% − 0.0%	
LECITHIN	0.50% + .50% − .25%	

C. OVERCOAT:
CHEMGLAZE II (OIL FREE ALIPHATIC MOISTURE CURE) POLYURETHANE COATING.
A 2.0±0.5 MIL THICK (APPLICATION TECHNIQUE SHALL INSURE COMPLETE COVERAGE OF SURFACE FREE OF PIN HOLES).

2. THE FINENESS OF GRIND OF THE MIXED INTUMESCENT COATING SHALL BE BETWEEN 0 AND 1.

3. ADVISORY PROCEDURE FOR APPLICATION OF THE INSUNOL INTUMESCENT COATING SYSTEM IS GIVEN IN AS2668.

4. DRYING TIME OF THE INTUMESCENT COATING MIXTURE IS DEPENDENT UPON APPLICATION TECHNIQUE. FAILURE TO REMOVE SOLVENT CAN CAUSE BLISTERING AND CRACKING.

(C2) 5. PRIOR TO USE OF THE INTUMESCENT COATING MIXTURE A BATCH SAMPLE SHALL BE TESTED FOR INTUMESCENCE. ONE CAN OF THE INTUMESCENT COATING MIXTURE FROM EACH PACKAGED BATCH SHALL BE SELECTED AT RANDOM FOR TESTING. THE INTUMESCENT COATING MIXTURE IN THE SELECTED CAN SHALL BE THOROUGHLY MIXED USING ANY METHOD THAT ALLOWS REDISPERSION OF PIGMENT WHICH HAS SETTLED DURING SHIPMENT OR STORAGE. THE THOROUGHLY MIXED INTUMESCENT COATING MIXTURE, IN SUFFICIENT QUANTITY TO GIVE A DRY COATING THICKNESS OF 30±3 MILS, SHALL BE APPLIED BY BRUSH OR SPRAY TO A SOLVENT CLEANED STEEL OR ALUMINUM PANEL HAVING MINIMUM DIMENSIONS OF 3"X6"X20 GAGE. THE COATING SHALL BE ALLOWED TO AIR DRY FOR 1/2 HOUR MINIMUM AND THEN BAKED FOR 1/2 HOUR MINIMUM AT 140°±5°F. IF NO BAKING FACILITIES ARE AVAILABLE, THE COATED PANEL MAY BE

SOURCE OF SUPPLY:
PARLON - HERCULES POWDER CO., WILMINGTON, DELAWARE 19899
PLIOLITE - GOODYEAR TIRE AND RUBBER CO., AKRON, OHIO 44316
PHOSCHEK - MONSANTO CHEMICAL, ST. LOUIS, MISSOURI 63166
CHLOROWAX - DIAMOND ALKALI, CLEVELAND, OHIO 44115
BENTONE 38 - NATIONAL LEAD, NEW YORK, NEW YORK 10006
ALTERNATE: THIXCIN - BAKER CHEMICAL CO., (SUBSTITUTE FOR BENTONE) PHILLIPSBURG, N.J. 08865
TOLUENE - TT-T-548
XYLENE - TT-X-916 GRADE A
MELAMINE - EASTMAN KODAK CO., EASTMAN ORGANIC CHEMICALS, ROCHESTER, N.Y. 14650
TiO_2 - N. F. GRADE
LECITHIN - MIL-L-3061
CHEMGLAZE II - HUGHSON CHEMICAL CO., ERIE, PA. 16512
TRIPENTAERYTHRITOL - TROJAN POWDER CO., ALLENTOWN, PA. 18105

NOTE 5 CONTINUED
AIR DRYED FOR 4 HOURS MINIMUM, AFTER BAKING OR DRYING THE COATED PANEL SHALL BE TESTED FOR INTUMESCENCE BY USING A BUNSEN BURNER ADJUSTED TO MAXIMUM HEAT. THE TEST PANEL SHALL BE HELD WITH THE BUNSEN BURNER FLAME ABOUT 2" AWAY FROM THE UNCOATED SIDE. THE TEST PANEL SHALL BE HELD IN THIS POSITION UNTIL INTUMESCENCE OCCURS (ABOUT 2 MINUTES) AND THEN TURNED OVER AND THE CHARRED SIDE EXPOSED TO THE FLAME UNTIL MAXIMUM INTUMESCENCE OCCURS (ABOUT 3 MINUTES). THE TEST PANEL SHALL THEN BE ALLOWED TO COOL AND THE CHAR HEIGHT OF THE INTUMESCENT COATING MEASURED. AN ACCEPTABLE BATCH OF INTUMESCENT COATING MIXTURE SHALL PRODUCE A MINIMUM CHAR HEIGHT OF 1.0 INCH. FAILURE OF A SAMPLE OF INTUMESCENT COATING MIXTURE TO MEET THIS CHAR HEIGHT REQUIREMENT SHALL CAUSE REJECTION OF THE BATCH OF INTUMESCENT COATING MIXTURE FROM WHICH THE SAMPLE WAS TAKEN. LOTS SHALL BE RE-INSPECTED PRIOR TO USE IF STORAGE TIME EXCEEDS 6 MONTHS.

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DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
U.S. NAVAL ORDNANCE LABORATORY

INSUNOL INTUMESCENT COATING SYSTEM

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13. ABSTRACT
(U) Both experimental and theoretical investigations have been performed on ways of extending the cook-off times of the Nose Fuze M904E2 and M148 Adapter Booster when engulfed in a liquid hydrocarbon fire. Several insulative materials were examined for utilization in fuzes and adapter booster fixes. The materials showing the greatest promise when fabricated into sleeves were Candidates No. 10 and No. 14. These materials extended the cook-off times of the Fuze M904E2 with deflagration being the usual reaction. An open Adapter Booster problem was determined to exist. When the Adapter Booster was unprotected and flame was directed into the open cavity, cook-off resulted in approximately four minutes. When the Adapter Booster was protected with intumescent paint on the adapter ring, and a disc and washer of Candidate No. 10 was inserted into the booster cavity, times in excess of 12 minutes were obtained. When the two fixes were combined the times to cook-off, with a somewhat lower fire temperature, were in excess of 12 minutes with detonation being the reaction. This report describes the cook-off test procedures and discusses the laboratory and field results of cook-off fixes for Fuze M904E2 and M148 Adapter Booster.

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